Imperfect Partnership: Effects of Collaboratories on Scientists from Developing Countries

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Information)
in The University of Michigan
2008

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For

Eleanor and Evan Park

ACKNOWLEDGEMENTS

I would have been unable to finish my dissertation without tremendous support and encouragement from many individuals.

I would like, first and foremost, to thank my adviser, Professor Judy Olson, for her excellent guidance and sustained support throughout my time in graduate school and during my completion of this thesis. It is difficult for me to list all that I have learned from her. Her insightful comments helped sharpen my mind and improve my writing. Her advice on how to conduct rigorous research and how to balance work and family life will benefit me my whole life. She kept me focused throughout the process, providing the support I needed.

My special thanks must go to Professor Michael Cohen. Michael's insights and well thought questions always turned my wild thoughts into clearer research questions and motivated me to achieve more than I had anticipated. Michael's intellectual achievements, humility and enthusiasm for teaching set good examples for my future career life. Meetings with Michael also have the benefits of enjoying cups of warm tea in the cold Michigan winter, creating precious memories of my life in Ann Arbor.

I was very grateful that Professor Steven Jackson agreed to become involved in this project. Steve pointed me to so many interesting and helpful readings that I had never thought would be related to my research. His expertise in qualitative research and sociology of science studies has broadened my view and helped improve the quality of my work.

I must thank Professor Fiona Lee for her assistance in this thesis. Her valuable advice has strengthened my study. In particular, her critical challenge in the early phases of this project helped me narrow down my research questions, enabling me to set up a feasible and attainable goal.

In addition to my committee members, many others offered valuable assistance in my research. Professor Gary Olson was always a source of mentoring and advice. I also want to thank Dr. Nathan Bos who gave me valuable suggestions in the early phases of the project. I am particularly indebted to Dr. Ann Zimmerman who was never too busy for a chat to provide thoughtful comments and advice on the construction of a theoretical framework and techniques of conducting interviews. Professor Ching Kuan Lee for the Department of Sociology offered me much valuable guidance on how to design and conduct a qualitative study, as well as on career development. Professor Soo Young Rieh and Professor Yan Chen offered me enormous encouragement and emotional support. My fellow doctoral students in the Rackham Interdisciplinary Workshop for Qualitative Research in the Social Sciences, Brian Hilligoss Jeannie Thrall, Pilar Horner, Carla Pfeffer, Katherine Luke, and Brian Girard made helpful comments on my very early draft. I also wish to thank Dr. Homer Neal, Dr. Zhengguo Zhao, Dr. Bing Zhou, Dr. Steven Goldfarb and Mr. Jeremy Herr from the Physics Department for their help in arranging my research trip to CERN, Europe.

This research would not have been possible without the cooperation and participation of the individuals I interviewed. I want to extend my thanks to all of them for sharing their experiences. Their dedication to science impressed me deeply and confirmed the value of my research.

I also wish to thank all the administrative staff at the School of Information. Ms. Sue Schuon and Ms. Xiaowen Zhou were sources of constant support. Ms. Sharon Mahoney, Ms. Christine Eccleston and Ms. Ann Verhey-Henke offered me assistance whenever needed.

I feel very fortunate to have the opportunity to meet and get to know my fellow graduate students at the School of Information. Jihyun Kim deserves special mention for her willingness and patience to listen and provide support, but I also want to thank Yan Qu, Xiaolong Zhang, Jun Zhang, Yong-mi Kim, Derek Hansen, Tapan Khopkar, Nikhil Sharma, John Lin, Matthew Bietz, Christopher Lee, Cliff Lampe, Jennifer Lee, and Erik Johnston.

I also want to thank my friends, Ms. Wonju Kwan in Korea, Ms. Barbara Fichtenberg and Dr. Norman Fichtenberg, Dr. Margaret Baker, Ms. Naomi Schult and Dr. Mark Schult. They helped to keep me strong and keep my faith.

My deepest appreciation goes to my family. My husband, Yongseok Park, a busy graduate student himself, offered me unconditional support and whatever help I needed. I want to thank my daughter, Eleanor Park, for growing into a wonderful three year old in spite of her mother spending much time away from her, and for understanding that Mom was sometimes busy with her dissertation work and could only read one book to her instead of five as she wanted. I want to thank my son, Evan Park, who stayed every minute with me while I was writing my dissertation. And last but not least, I thank my parents, Jiyu Cui, Mingjie Luo, and my sister, Aihua Luo for their steadfast encouragement and support.

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ABSTRACT

Academic research and various reports from research institutions and governmental agencies have consistently indicated a gap in the scientific output of developing and developed countries. Researchers and policy makers are trying hard to reduce the disparity. In recent years, researchers have hypothesized that a new form of scientific collaboration--the "collaboratory"--holds promises to greatly benefit scientists from developing countries. It is argued that distributed collaborations enabled by various information technologies can allow scientists from developing countries to reach remotely located experts, instruments, and databases that their local institutions cannot afford. However, there have been no empirical studies to prove or disprove this.

Prior studies of the impact of information technology on scientific work tend to focus on the correlation between technology use and scientific productivity as measured by publications and citations. This approach ignores the mediating factors affecting the relationship between information technology use and scientific productivity. As a result, we are not clear about the dynamics through which information technology exerts its influence. Neither do we understand how information technology enhances productivity, if it indeed does so. Thus, the current study focuses on some mediating factors that purportedly lead to productivity, such as scientists' access to resources and participation in communities of practice.

Adopting a qualitative approach (interviews complemented by field observation), I explore how scientists from developing countries benefit from reaching remotely located resources and participating in communities of practice in the virtual organization of a collaboratory. I also demonstrate how the relation of resource dependency, the nature of collaborative work, geographical distance and cultural differences influence scientists' participation in collaborataries. These factors affect the ability of scientists from developing countries to access resources of collaboratories, build relationships with other collaboratory members and learn knowledge and practice from their collaborators in the developed world. In addition, I show that collaboratories facilitate technology transfer from scientists from developed countries to those from developing countries. However, scientists from developing countries demonstrate an urgent need to build general competence in performing research. This kind of competence can only be achieved through long-term exposure to the practices of advanced laboratories from the developed world. Collaboratories failed to meet the need because of their project-oriented nature and their funding mechanism.

CHAPTER 1

INTRODUCTION

In 2003, Kofi Annan, the Secretary-General of the United Nations, called attention to the clear inequalities in science between developing and developed countries. Mr. Annan asserted that “This unbalanced distribution of scientific activity generates serious problems not only for the scientific community in the developing countries, but for development itself” (2003). Annan's sentiments have also been validated by a recent report on world science by academic research and various reports from research organizations and governmental agencies, which present overwhelming evidence for the disparity in scientific output between the developing and already developed countries. Annan's sentiments have also been validated by various reports from research institutions and governmental agencies. For example, in 2001, developed countries accounted for 87.3 percent of scientific and technical publications registered by the Science Citation Index (SCI). North America and the European Union clearly dominated the number of scientific publications produced annually, with 36.2% and 40.3%, respectively

Despite the disparity of scientific output between developing and developed countries, there are many compelling reasons to increase scientific contributions from the developing world (Holmgren & Schnitzer, 2004): Science, as a discipline, would benefit more from the contributions of many diverse groups than being dominated by groups from only two geographical areas. Many research problems would be solved more easily by including the efforts and insights of scientists from developing countries. For example, research in climate change and biodiversity research urgently requires inputs from scientists in the developing world. It is also critical for developing countries to promote their research capacity and apply scientific knowledge to solve problems of great social concern, such as food security, diseases like AIDS, pollution and etc.

Many researchers and policy makers seek to reduce this disparity. In recent years, the Internet and related information technology have become increasingly important in scientific work. People have argued that information technology has brought about new opportunities to narrow the productivity gap between scientists of developing and developed countries.

In particular, over the last decade, a new form of scientific organization, the "collaboratory," has been more and more widely adopted. A collaboratory is "an organizational entity that spans distance, supports rich and recurring human interaction oriented to a common research area, and provides access to data sources, artifacts and tools required to accomplish research" (G. M. Olson, Bos, & Zimmerman, 2008). An example of a collaboratory is the Function Biomedical Informatics Research Network (Function BIRN), where 186 participants from 11institutions participate in work to study brain dysfunctions related to the progression and treatment of schizophrenia (J. S. Olson, 2008).

As shown in Figure 1, the capabilities of a collaboratory include technology that connects people with people, technology that enables access to information and computation, and technology that enables access to facilities. Technologies that connect people with people include computer mediated communication technologies, such as email and tools for video or teleconferencing. Technologies that enable access to information and computation include World Wide Web, digital libraries and grid computing. Technologies that enable access to facilities include data viewers that display the current modes and status of remote instruments as well as services that provide scientifically critical data (T. A. Finholt, 2002; G. M. Olson et al., 2008).

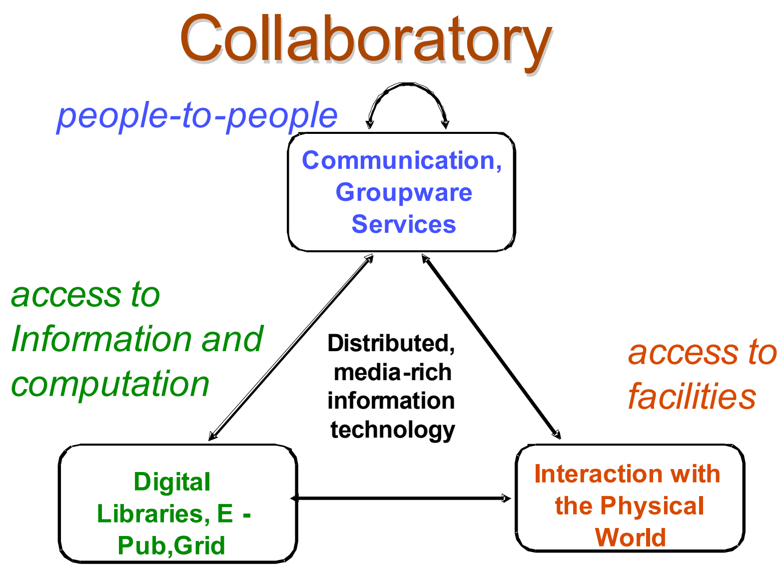

Figure 1 Collaboratory

Collaboratories transform geographically bounded laboratories into virtual organizations with the hope of advancing science in two ways: by increasing the number of participants and increasing the diversity of approaches. One way to broaden participation is to reach out to scientists in developing countries. In particular, researchers have hypothesized that collaboratories hold promise to greatly benefit scientists from developing countries by allowing them to reach remotely located experts, instruments, and databases (T. A. Finholt, 2002). While many hope this transformation represents progress, we do not yet know to what extent this is the case. We need to understand how collaboratories, which adopt various information technologies to support distributed scientific collaboration, affect scientists from developing countries.

Indeed, many prior studies have considered the impact of information technology on scientific work. However, these studies tend to focus on the correlation between technology use and productivity as measured by publications and citations (Cohen, 1996; Duque et al., 2005; Hesse, Sproull, Keisler, & Walsh, 1993; Walsh & Maloney, 2002). This approach ignores the mediating factors affecting the relationship between information technology use and scientific productivity, such as scientists' ability to access resources and participate in communities of practice. As a result, we are not clear about the dynamics through which information technology exerts its influence. We do not understand how information technology enhances productivity, if indeed it does. In addition, collaboratories are a relatively new phenomenon, and it takes time for publications and citations to emerge. Thus, the current study focuses on some mediating factors that purportedly lead to productivity, such as scientists' access to resources, participation in communities of practice (M. F. Fox, 1991). These factors appear earlier than do publications in scientific work.

It is also notable that most of the studies of the relationship between information technology have examined the impact of information technology on the work of scientists from developed countries (Cohen, 1996; Hesse et al., 1993; Walsh & Bayma, 1996; Walsh, Kucker, Maloney, & Gabbay, 2000; Walsh & Maloney, 2007). Most collaboratories have also been designed for the practices of scientists from the developed world. Little is known whether they meet the needs of scientists from developing countries. We argue that differences between scientists in developing and developed countries will affect the use of collaboratories by scientists from developing countries. Scientists from developing countries tend to have a poorer communication infrastructure, a higher teaching load and less time for research work (Luo & Olson, 2008; Riddoch, 2000). The institutions they work for might not encourage research and publication as much as do the big research universities in the US. Scientists from developing countries might have different expectations for collaboratories, or they might benefit from collaboratory use in different ways from scientists in the developed world. Because of this, we might need to design collaboratories differently for this population. Thus, in order to understand the influence of collaboratories on scientists from developing countries, and design collaboratories that can serve their needs better, we must understand the processes of scientific research, and the values of scientific communities in developing countries.

In this study, I first identify environmental factors that influence scientific productivity and then discuss how collaboratories change the way that these factors play out, and how these might differ for scientists from developed and developing countries. As reviewed in the literature in the next chapter, the important environmental factors that lead to scientific productivity include reaching resources and participating in communities of practice. Factors that affect participation in communities of practice include how community members build relationships with each other and how knowledge and practices are transferred among community members. Adopting a qualitative approach (interviews complemented by field observation), I explore how scientists from developing countries benefit from reaching remotely-located resources and participating in communities of practice in a virtual organization like a collaboratory. I also demonstrate how the relation of resource dependency, the nature of collaborative work, geographical distance and cultural differences influence scientists' participation in collaborataries. These factors affect the ability of scientists from developing countries to access resources of collaboratories, build relationships with other collaboratory members and learn knowledge and practice from their collaborators in the developed world. In addition, I show that collaboratories facilitate technology transfer from scientists from developed countries to those from developing countries through supporting communities of practice. However, scientists from developing countries demonstrate an urgent need to build general competence in performing research. This kind of competence can only be achieved through long-term exposure to the practices of advanced laboratories from the developed world. The project-oriented nature of collaboratories and the funding mechanism have failed to support this need.

This dissertation ultimately aims to inform better collaboratory design, of both their technology and social practices, to fit scientists from developing countries. A better design will be based on a better understanding of factors leading to scientific productivity and the needs of scientists from developing countries.

The dissertation is organized into five chapters, including this introductory chapter. Chapter 2 is a literature review in which I define environmental factors leading to scientific factors, how a collaboratory may change these factors, and describe a research framework and research questions for the study. Chapter 3 describes methods used in the study and introduces the seven collaboratories studied. In Chapter 4, I report the findings of the study. Chapter 5 discusses the limitation of the study, and the implications of the findings for policy making and for future collaboratory design.

CHAPTER 2

LITERATURE REVIEW

In this chapter, I first review the literature of the sociology of science, identifying environmental factors influencing scientific productivity. Then I review the literature of Computer Supported Cooperative Work (CSCW), organization studies and communities of practice to find out socio-technical factors that influence the environmental factors leading to scientific productivity. The chapter also introduces the literature about the working environments of scientists from developing countries and collaboration between scientists from developing and developed countries. This chapter concludes with a research framework and research questions for the study.

ENVIRONMENTAL FACTORS AND SCIENTIFIC PRODUCTIVITY

Studies of the sociology of science have consistently found that organizational environments, including types of doctoral programs one attends and types of institutions where one works, provide structures affecting scientists' performance.

Graduate school is a critical socializing environment, where scientists develop knowledge, skills and competences, and where the scientists' habits and values are cultivated. The prestige of the graduate school one attends predicts his/her future productivity. For example, Crane (1965) interviewed 150 scientists and measured the scientists' productivity from different fields (biologists, political scientists, and psychologists) from three universities of various levels of prestige[1]. Her data analysis shows that scientists graduating from major universities tend to be highly productive regardless of their current working environments. By contrast, scientists trained at minor universities are unlikely to be highly productive unless they are currently working in a major university. According to Crane, graduates of minor universities are less productive because they are trained by less productive and less prestigious advisors. They are less likely to participate in a productive research area or learn from their advisors and colleagues the optimal way to proceed in developing a research program. Sometimes students of minor universities cannot develop their research interests because the graduate schools cannot afford the instruments or other resources they need for their research.

In her study of chemists, Reskin (1979) finds that both their departments and advisers affect graduate students' later performance. Training and collaborating with a productive advisor is more important for scientists to start publications during the pre-doctoral period, while the prestige of the doctoral program is important for their continued productivity in the post-doctoral period.

[1] The three universities studied by Crane were selected from the top stratum of American educational institutions. One university was a major institution with a long tradition of graduate education and research activity. The second was a smaller institution with a tradition of research activity in some but not all its departments. The third institution was a state university that had begun to offer graduate degrees shortly after World War II. Its faculty had been expected to do scientific research not long before the study was conducted.

Chubin et al (1981) extends the examination to other scientists in fields of electrical engineering, physics, psychology, sociology, zoology and biochemistry. Their data also reveal that the prestige of the doctoral program predicts publication productivity.

Some other researchers have studied the influence of scientists' current institutions on their productivity. Long's (1978) longitudinal study clarifies the causal relationship of "selection effect" and "departmental effect." It untangles whether the prestige of a scientist's location is determined by a scientist's productivity or whether a scientist's productivity is determined by the organizational context. Through examining the change in the productivity of a scientist when he/she moved from either graduate school or a postdoctoral fellowship to his/her first academic jobs and when he/she moved from one institution to another, he finds that the effect of scientists' productivity on location is weak, but the influence of organizational context on productivity is strong. For scientists moving into their first positions, their initial productivity is affected by factors related to their graduate education, such as sponsorship, postdoctoral study and etc. However, over time organizational context becomes the dominant predictor of productivity. After the third year on the job, productivity is more strongly related to prestige of the department than to previous doctoral position. Particularly, those in prestigious institutions increase their publication and those in less prestigious departments publish less. Thus, it is concluded that a scientist's productivity does not significantly affect his/her location. However, organizational prestige is a strong predictor of scientific productivity.

Long and McGinnis (1981) extend Long's (1978) study to include non-academic settings such as research institutions. They again find the strong effect of organizational context on scientific productivity. Their research results indicate that affiliation with a non-research oriented college or industry results in lower publication rate as compared to affiliating with a research university.

Another study conducted by Allison and Long (1990) further extends previous studies to include scientists from different fields and examines not only scientists' first jobs but also their productivity after their job change. They compare the productivity of chemists, biologists, physicists and mathematicians who move up and move down in terms of the prestige of institutions. For each mobility group, they calculate mean counts of publications and citations before and after the move. They find that those who are upwardly mobile display a significant increase in their rate of publication and citation. By contrast, for those who move downward, the rate of publication is noticeably lower after the move. This adds to the evidence that institutional affiliation has a stronger effect on productivity than productivity on the institutional one is affiliated with. The series of studies conducted by Long and his colleagues are important in that they have proved that the prestige of institutions is positively related to scientific productivity even after other influencing factors are controlled.

Research about the positive relation between the prestige of scientists' graduate schools or their current institutions and scientific productivity has proved that scientists' productivity is affected by their working environments. Prestigious institutions promote productivity, while non-prestigious institutions often fail to do so. However, this line of literature does not clarify what environmental factors lead to the productivity difference between scientists from prestigious and non-prestigious institutions.

WHAT DO LABORATORIES AFFORD SCIENTISTS

In order to identify the influencing environmental factors, we need to go first to literature of sociology of science to examine what laboratories afford scientists.

Laboratories as Places and Organizations Providing Resources

In the modern history of scientific research, laboratories function as social organizations as well as physical settings (T. A. Finholt, 2002).

First, as a place, a laboratory concentrates into one place essential but costly equipment that can be shared by many scientists. Concentration of equipment at laboratories offers one way to maximize investments in research. As an organization, a laboratory enables scientists to share resources, such as funding and qualified manpower. In their ethnographic work, Latour and Woolgar (1986) find that the ability for a scientist to do research depends on how successful his/her colleagues are at recruiting funding. They describe how directors of laboratories spend most of their time traveling and presenting to secure funding for their research labs, while junior researchers who did not have enough credibility to attract funding rely on the funding drawn by the senior researchers.

The important role that laboratories play in concentrating equipment and recruiting funding and other resources also helps to explain the productivity difference between scientists from prestigious and non-prestigious institutions. Many scholars argue that the prestige of institutions influence the amount of research resources available to the institutions (P.D. Allison & Stewart, 1974; Crane, 1965; M. F. Fox, 1991; Hargens & Hagstrom, 1967; Zuckerman, 1988). They find that highly recognized scientists and institutions are more successful in obtaining resources for future research. These resources include tangible resources, such as laboratory facilities, computer hardware, library holdings, as well as less tangible ones, such as graduate student ability and time were granted 21% of all the funds available to American colleges and universities in 1979-1980 with the next 20 having an additional 43%, leaving the remaining 2950 or so institutions to share the remaining 36%.

Laboratories as Places and Organizations Providing Communities of Practice among Scientists

An increasing number of investigators with ethnographic orientations have studied scientists and technicians in their everyday work in various scientific domains, such as astronomy (Lynch & Edgerton, 1988), biochemistry (Knorr-Cetina, 1981), marine science (Goodwin, 1995), microbiology (Latour & Woolgar, 1986), neuroanatomy (Lynch, 1985), and particle physics (Traweek, 1988). These ethnographic studies of scientists have revealed that scientific research and its products are situationally contingent achievements involving scientists, technicians, granting agencies, politicians, tools and instruments, organizational cultures, cultures of various scientific communities, and so on. In this dissertation, I review the literature studying biologists and high energy physicists, whose collaboration in collaboratories is the focus of my dissertation.

High Energy Physics

The goal of high energy physics is to search for the fundamental particles and forces which build the world around us. Since these particles cannot be seen directly, physicists build complicated detectors in which the particles register their activities. The detector is hit by particles and converts their impact into electrical currents and pulses that may be interpreted as physical processes. Scientists then begin their analyses with representations of the detector—what they call "offline" manipulations of the signals extracted from detectors after data have been acquired (in contrast, online manipulations are manipulations during data collection). These representations reconstruct the events in the detector, shaping these signals into forms that echo the particles of interest to physicists. Successful reconstructions of physical events in the detector are premised on the understanding that scientists are deeply familiar with the detector and all other components of the measurement apparatus. Thus, the detector functions as a center point of research in high energy physics. In fact, in an experiment, more time is spent on designing, building, and installing the detector's components, and in particular on examining and testing every aspect of their working, than on handling the data it eventually produces (Knorr-Cetina & Karin, 1999; Traweek, 1992).

The scale and cost of the detector determines that research projects in high energy physics must be collaborative ones. These projects need to draw funds and manpower from various institutions. For example, in ATLAS, after the completion of Research and Development, different components of the detector were built in participant countries before being shipped to the European Organization for Nuclear Research (CERN), where the detector was assembled. Consequently, at the initial stage of detector-building, scientists from different institutions need to communicate with each other to coordinate work related to redesigning, examining, testing and installing the detector. At the subsequent stage of analysis, the physicists begin their task of deciding what part of their data can be considered valid and what must be "cut," discarded as "noise." However, interpretation of data taken from the detector is far from straightforward. It depends on scientists' understanding of the detector's components and processes. Because of the large scale of the detector, it is difficult for a physicist to have full knowledge of every component of the detector. In fact, physicists "are characterized and identified in terms of the objects on which they work" (Knorr-Cetina & Karin, 1999)They tend to only have deep knowledge of a single, or a few components of the detector, on which they have been working. Consequently, physicists must seek each other's help for the knowledge of other parts of the detector and the particular particles they register. In the final stage, physicists obtain the results of analysis. These results must be shared and scrutinized by the community of collaborators, and also confirmed by data from other experiments—a process that depends upon persuading the community the significance of these results. (Traweek, 1988).

The collaborative nature and the large scale of high energy physics also determine that the evaluation of individual scientists' performance is different from that in many other scientific fields. In many fields, scientists' output is evaluated by scientific productivity as measured by the number of publications and citations. By contrast, in high energy physics, the authorship of a paper belongs to the collaborative project, which means that a paper may have a few hundred, or even a thousand authors, and the order of the authors' names does not indicate the importance of a person's contribution. Instead, scientists display their individual contributions at various occasions in the working process: they can take leadership of sub-projects; they can offer ideas in informal discussions; they can show their problem-solving ability when the detector malfunctioned; they can show their competence through presentations at various workshops and conferences.

Thus, communication plays a critical role in the operation of the community of high energy physics. They enable scientists to fulfill various tasks: scientists evaluate each others' work during their informal conversation; they establish and maintain relationship with others; they access experts' knowledge; they gain from others corroboration for their research results; they display their research ability. In addition, informal communication enables junior scientists to become familiar with successful stories of senior scientists, which they can use as role models for their own career. Thus, acquiring the capacity to access communication about physicists, data, detectors, and ideas is necessary in the training of high energy physicists.

Biology

Different from high energy physics, where the focus of research is the representations of physical phenomena acquired from the detectors, biological research centers upon interaction with natural objects, such as living cells, molecules in cells and so on. Scientists employ various instruments to conduct experiments on plant and animal materials, which are sometimes cultivated and nurtured by scientists in the laboratory. When conducting experiments, scientists based their work on protocols, which specify many steps, sub-steps and sub-substeps of manipulation through which work should proceed.

Since biologists study living organisms that react differently to experimental treatments, biological research is situationally contingent. Although scientists follow laboratory protocols to conduct experiments, in their practice, they often find themselves interpreting and enacting the protocol based on the reactions of the materials and living organisms. Scientists commonly experience various degrees of failure in experimental work. Confronted with problems, the general strategy they therefore adopt is "blind variation" (Knorr-Cetina & Karin, 1999). Thus, when facing unexpected reactions, biologists do not prioritize a perfect understanding of the cause of the problem. Instead, they will try various methods until one of the variations enables them to find workable results. Effective methodologies, or procedures of "making it work" are passed on "without an exhaustive rationalization of exactly how they work in all of their aspects" (Lynch, 1985). The lack of rationalization of experimental procedures creates local knowledge composed of the largely inaccessible idiosyncrasies of individual researchers or laboratories (K. Knorr-Cetina, 1981). These individual researchers or laboratories have their own customized research practices, which they seldom report in their published papers. Scientists acquire the local knowledge of a laboratory through collaboration and informal communication. Scientists can also acquire the local knowledge of other labs through informal communication at conferences (K. Knorr-Cetina, 1981).

In addition, when scientists try to evaluate the status of experimental processes and determine subsequent methods, they use their sensory faculties as instruments of inquiry. They depend on what they see and what they smell to determine the methods to adopt for the next step. Thus, experimental work is skilled manual labor that requires the involvement of bodily senses and activities. Experience in performing experiments is like experience in practicing art, in which expertise requires the mastery of special ways of seeing and doing things. The "experienced body" of a scientist "silently remembers and performs" (Knorr-Cetina & Karin, 1999). However, because it is tacit, the knowledge that allows scientists to use their sense organs to make judgments and decisions is difficult to codify.

One of the most efficient ways laboratories preserve the experiences of their practice is via their narrative culture, or more specifically, their story telling (Brown & Duguid, 1991; Knorr-Cetina & Karin, 1999). While instructions and protocols only give scientists the rules, stories maintain some part of the experiential context by preserving the "scenic" and "phenomenal" aspects of events. They also convey the sense of original sequences of behavior and events, which may occur again in appropriate occasions. Thus, stories not only inform scientists as to what to do, but also why problems may occur. When scientists face similar problems, stories enable them to build a causal map from the experiences of other scientists. In laboratories, the stories circulate and keep the relevant experience alive, becoming a sort of communal stock of knowledge (Knorr-Cetina, 2003).

COLLABORATION AND SCIENTIFIC PRODUCTIVITY

Given the factors that affect scientific productivity discussed above, it is not unreasonable to conclude that scientists' productivity depends not only on their education and working environments, but also their collaboration with people outside their own organizations. Inter-organizational collaboration might enable scientists to overcome the restrictions of their own organizations and reach resources and experts located in other institutions, thus changing scientists' working environments.

Prior studies indicate that collaboration is positively correlated to productivity. For example, the frequently quoted research conducted by Price and Beaver (1966) states that among the 592 scientists studied, the most productive scientist has the largest number of coauthors. Through interviewing 41 Nobel laureates in science, Zuckerman (1967) finds that laureates publish more and are more collaoborative than a matched sample of scientists. Other studies specify the impact of inter-organizational collaboration. In their study of Canadian scientists' publications in the years of 1980, 1985, 1990 and 1995, Godin and Gingras (2000) find that the most productive scientists collaborate with scientists from other sectors. For example, the most productive scientists from universities tend to collaborate with those from those in industry. In their study of publications of scientists from New Zealand, Goldfinch and his colleagues (Goldfinch, Dale, & Derouen, 2003) conclude that the number of authors, countries and institutions involved is positively correlated to the expected citation rates. Some studies also show that for those scientists from less developed countries, collaboration with scientists from scientifically developed countries tends to improve the citation rates of their publications (Goldfinch et al., 2003; Bordons et al., 1996).

The general consensus as to why collaboration may increase productivity includes access to expensive or unique equipment or dataset (Meadows 1974; Thorsteinsdottir, 2000; Melin, 2000), integration of special expertise and knowledge (Thorsteinsdottir, 2000), transferring tacit knowledge and knowledge of technique (Beaver and Rosen, 1978, 1979a), and mentoring graduate students and postdoctoral researchers (Bozeman & Corley, 2004). Thus, scientists expect to rely on collaboration to overcome the limitations of their immediate environments and thereby access resources, expertise and knowledge.

Despite the positive correlation between collaboration and scientific productivity identified by some previous studies, it is also found that collaboration does not always increase productivity. In their analysis of the curriculum vitae and survey responses of 443 academic scientists, Lee and Bozeman (2005) find that the total number of a scientist's research collaborators is positively related to the number of refereed articles and books published. The relationship between collaboration and productivity is robust even after all other factors (such as age, rank, status, research grants and contracts, gender and family relations, citizenship, job satisfaction, perceived discrimination, and collaboration strategies) are accounted for. However, their study also shows that the number of collaborators is not correlated to publishing productivity by "fractional count," in which coauthored papers are divided by the number of authors. They conclude that there is a great deal of variance in the relationship between collaboration and scientific productivity; that is, not every collaboration can enhance productivity, and a collaboration does not always enhance the productivity of every party involved. Lee and Bozeman's statement has been validated by other empirical data. For example, Cummings and Kiesler (2005) find that multi-university collaboration poses more problems than multi-disciplinary collaboration, because of more transactional costs involved. Duque et al. (2005) show that collaboration suppresses productivity in developing areas, possibly because of the greater costs required for communication and coordination. In their analysis of collaborative patterns in chemistry at both the individual and the group level, Pravdic and Oluic-Vukovic (1986) find that collaboration with scientists of high productivity generally increases personal productivity, but collaboration with those of low productivity tends to decrease it. It indicates that in a collaboration between a less experienced and an experienced scientist, while the productivity of the less experienced may be enhanced, that of the experienced scientist may be compromised.

Given the complexity of the relationship between collaboration and scientific productivity, Lee and Bozeman (2005) propose further studies on how the relevant personal and environmental factors influence the way in which collaboration affects scientific productivity. For example, what are the dynamics of collaboration-seeking, that is, is it that lower-status scientists seek to collaborate with higher-status ones? How do the dynamics affect the productivity of each party involved? What are the factors resulting in more transactional costs in collaboration? What is the value added by collaboration and does the value offset the transactions costs?

INFORMATION TECHNOLOGY, REMOTE COLLABORATION, AND PRODUCTIVITY

As shown above, since collaboration is correlated to scientific productivity, information technology should be another significant factor that can affect productivity, because information technology can facilitate distributed collaboration whereby scientists interact with others outside their own organizations and reach remotely located resources and experts.

Indeed, prior research has shown a positive relation between information technology and productivity. Some studies demonstrate that computer mediated communication is positively correlated with scientific productivity (Bishop, 1994; Cohen, 1996; Hesse et al., 1993; Kaminer & Braunstein, 1998; Walsh et al., 2000). Hesse et al.

(1993)'s research examines ocean scientists' use of a collaboratory called SCIENCEnet. SCIENCEnet supports mailboxes in 45 countries and distant locations including Antarctica; it also provides fee-for-service access to database indices, services and colleagues. A positive relationship was found between the use of ScienceNet and scientific productivity. However, the data collected for these studies are cross-sectional, and it is difficult to understand the direction of relationship. That is, it is unclear whether the use of information technology leads to improved scientific productivity or scientists with higher productivity tend to use information technology more frequently.

Previous studies also imply why Internet use may result in an increase in scientific productivity. One of the most significant impacts of computer networks is that it facilitates the formation of large and geographically distributed working groups and thus restructures communication pattern of community or organizational members (T.A. Finholt & Sproull, 1990; Wanda J. Orlikowski, 1994). In the area of scientific research, Walsh and Bayma (1996) find that the Internet has changed the pattern of scientific collaboration: collaborations are becoming more frequent and more geographically distributed and communications within collaborations are also becoming more frequent. Other studies have shown similar results. Using social network analysis, Koku and Wellman's (2004)'s and Walsh and Maloney's(2002) research has indicated independently that email contact has resulted in larger and more heterogeneous collaborative networks. Koku and Wellman argue that as a supplement for face-to-face contact, contact through the Internet provides more avenues for fostering "social, instrumental, and emotional support, and the mobilization and coordination of collective activity" (p. 305). Walsh and Maloney attribute the feasibility of larger scientific collaborative networks to the lower overhead of maintaining relationship and increased time for interaction that network technologies make available. These studies indicate that information technology enables scientists to engage in communication and communities of practices with a larger group of collaborators outside their own institutions. However, they fail to address whether a larger scale of collaboration itself will cause problems, as Cummings and Kiesler found. In addition, it is difficult to define causal relationships in these studies. Both directions of causation (frequent email use leading to increased collaboration or more collaboration resulting in increased use of email) are possible.

Some researchers argue that information technology may help to improve scientific productivity because it can reduce the problems of collaborations. Through their survey analysis of US scientists, Walsh and Maloney (2007) conclude that email has a positive impact on overcoming problems of coordination, but does not reduce problems of culture or security.

Other research findings cast doubt on the statement that either collaboration or the use of information technology has a uniformly positive impact on productivity. Duque et al. (2005) examine the relations among Internet use, scientific collaboration, and productivity of scientists working in two institutional settings (universities and research institutes) in Kenya, Ghana, and Kerla of India. They find that the African scientists collaborate significantly more than Indian scientists, but their productivity is much lower. Those who are more collaborative also report more difficulties in research. However, when controlling for location, collaborators report no greater problems than non-collaborators. They also find that greater access to the Internet is correlated to fewer research problems. The Indian scientists enjoy greater access to the Internet and report fewer difficulties. They also involve themselves in fewer collaborations, but produce at twice the level of their African counterparts. Thus, the researchers speculate that collaboration can incur more research problems, which are an effect of local contexts. Because of their poorer social and technical infrastructure, African scientists tend to encounter more research problems in collaborations when they struggle to meet deadlines and report requirements of increased collaborations. By contrast, participating in fewer collaborations, scientists in Kerla avoid additional research problems, and thus reap pure productivity benefits resulting from access to the Internet. They conclude that "the conditions that render the relationship between collaboration and productivity problematic may also undermine the collaborative benefits of the Internet" (p777). The Internet contributes to the increase of scientific productivity only for those who can "take advantage of its problem solving attributes while keeping their collaboration stable" (p777).

In sum, previous studies indicate that collaborations enabled by information technology have the potential to influence scientific productivity through changing scientists' environmental factors. For example, information technology enlarges collaboration and provides scientists opportunities to engage in communities of practice with those outside their own organization. However, mediating factors affect the way in which information technology and collaborations produce effects. Thus, in order to understand how scientific work is influenced by collaboratories, in which collaboration is supported by various information technologies, we need to understand how these mediating factors interact with information technology and collaborations. We need to understand the environmental factors, such as resources and communities of practice, and then see how collaboration may affect the environmental factors and what are the mediating factors affect the way that collaboration can change these factors. Since the process of accessing resources is more intuitive, in next section, I will review literature on communities of practice and how information technology and collaboration may affect communities of practice.

COMMUNITIES OF PRACTICE

Though differences exist between the epistemic cultures of high energy physics and biological research, similarities can also be seen: First, in each culture, knowledge is situated, that is, knowledge is specific to particular situations. For example, high energy physicists to must learn skills for collaborative communication, such as whom to seek for help, how to communicate with specialists in different fields, etc.; likewise, biologists must acquire the sense and skills to conduct experiments, which are embedded in the body of experienced researchers. Second, both high energy physicists and biologists acquire situated knowledge through participating in real practices, whether in collaborative communication or laboratory experiments.

Learning in Communities of Practice

Lave and Wenger's (1991, 1999) theory of communities of practice (CoP) clarifies the process of how people acquire situated knowledge, and thus enables us to study the significance of its process within the scientific communities. According to Lave and Wenger, knowledge is "a matter of competence with respect to valued enterprises," and knowing is "a matter of participating in the pursuit of such enterprises." Knowing is enabled by a community of practice, which is defined along three dimensions (Wenger, 1999):

(1) It is a *joint enterprise*, the value of which is understood and continually renegotiated by its members.

(2) It involves *mutual engagement* in which members are bound into a social entity.

(3) It produces shared repertoire of communal resources (e.g., routines, sensibilities, artifacts, vocabulary, styles, etc.)

Lave and Wenger (1991) emphasize that a community of practice is “an intrinsic condition for the existence of knowledge,” and participation in the cultural practice is “an epistemological principle of learning “(p98).

Furthermore, Lave and Wenger (1991) label the informal learning process in a community as “legitimate peripheral participation” (LPP). People participate in communal learning at different levels depending on their experiences or level of authority, i.e., whether they are a newcomer or a long-term member to the community. When newcomers enter a community, they embark on a trajectory toward gaining full membership. They gain legitimate membership through beginning with peripheral practice, and their gradual mastery of these practices enables them to progressively increase their legitimacy within the community. The newcomers learn “how masters talk, walk, work, and generally conduct their lives,” and “how old-timers collaborate, collude, and collide, and what they enjoy, dislike, respect, and admire.” However, they are not mere observers; they contribute to producing and reproducing the community. In the process, they become identified with the community.

Cross-Communal Practices

Because Lave and Wenger (1991) only study self-contained single communities, their study only allows a discussion of the relationships between old-timers and newcomers. Consequently, other researchers have criticized Lave and Wenger’s (1991) simplified account of power relationships in a community (Cox, 2005; S. Fox, 2000). They point out that Lave and Wenger not only neglect the potential lateral power conflicts among old-timers and among newcomers themselves, but also fail to discuss the relationship among communities or between communities and other social entities (e.g. organization) as a source of change.

Wenger (1999) elaborates the concept of communities of practice by adding a discussion of identity:

> We all belong to many communities of practice, to some in the past, to some currently; to some as full members, to some in more peripheral ways. Some may be central to our identities; some incidental. Whatever their nature, these various forms of participation all contribute in some ways to the production of our identities (p165).

He argues that community members' identity extends along an axis of time and space. Along the time axis, we can see the inbound trajectory of community members' change; that is, they move from peripheral to center through "legitimate peripheral participation." Along the space axis, people belong to different communities, and their multimembership affects their participation and identity formation in every community in which they are involved.

Thus, people's learning in a community not only depends upon the power granted them to access old-timers, but also their ability to control what communities they belong to and what knowledge and meaning each community attributes to them.

However, because Wenger's (1999) empirical study still focuses on a single community (insurance claim processors), he fails to provide any evidence for his theoretical discussion of the impact of multimembership, and leaves his argument abstract. We cannot obtain a clear picture of the types of tensions and dependencies in cross-communal relations and their impact.

Inspired by Orr's (1996) ethnographic study of Xerox repairmen, Brown and Duguid's (1991) and Brown and Duguid's (2001) interpretation and application of communities of practice transcend the apprenticeship model of practice in a single community. They extend the theory of communities of practice to networks of practice

(NoP), which consist of people engaging in common practices. Brown and Duguid (1998) and Brown and Duguid (2001) argue that an organization consists of different NoPs interacting with each other. They also point out that an NoP can cross organizational boundaries; occupational networks are a good example of NoPs. What distinguishes an NoP from a CoP is that members of an NoP do not work together in an interdependent manner that requires them to coordinate their tasks accordingly. Members of NoPs tend to be more homogeneous, and thus we do not see different levels of participation. For example, Orr's (1996) repairmen belong to different departments of Xerox, and work in the field as individuals. Furthermore, in contrast to CoPs, where the existing knowledge and social structures were reproduced, NoPs emphasize finding solutions to novel problems through situated and improvised practices. For example, when facing crashed machines, the repairmen exchanged their "war stories" about how they solved the problems they had encountered before. In the process of story-telling, the repairmen's memory, tests conducted on the Xerox machines and the machine's responses interplay with each other, resulting in insights into final diagnosis and repair. Thus, an NoP helps to generate a communal knowledge through integrating knowledge distributed in individual participants.

Brown and Duguid (1991, 1998, 2001) also study how the relationship between communities and among communities and organizations affect communities of practice. In particular, drawing on Orr's (1996) study, they stress how an organization may oppress communities of practice by enforcing management orthodoxies. They give a detailed account of the tension between canonical and noncanonical practices; for example, the repairmen's communities of practice were stifled by canonical managerial practices, espoused perspectives, and abstract procedure accounts, such as those contained in various documents. They also discuss how an organization should facilitate knowledge sharing between different NoPs both within and between organizations. They argue that what hinders transfer is "stickiness" and "leakiness" of knowledge. On the one hand, knowledge is situated, which makes it "stick" to a local practice and difficult to be transferred to another community with a different environment, culture and personnel; on the other hand, when knowledge travels through the networks of practice, it will inevitably "leak" across organizations. Thus, to encourage knowledge transfer, it is important to understand and address the epistemic-social issues that influence the stickiness of different kinds of knowledge, as well as the psychosocial issues (such as levels of trust and motivation) that affect people's willingness to share knowledge.

Although Brown and Duguid discuss cross-communal practices and knowledge sharing, their conclusion is restricted by the fact that the empirical studies they build upon are studies of single communities—mainly the Xerox repairmen. We do not have a sense of the concrete benefits of and barriers to cross-communal knowledge transfer.

Facilitating Communities of Practice and Networks of Practice

In order to understand how to maintain communities of practice and networks of practice and facilitate cross-communal knowledge transfer, we need to be clear about their internal processes, that is, how knowledge is produced, maintained and accessed.

Lave and Wenger (1991) contend that knowledge is historically constituted, ant it resides in the daily routine practices of community members (what everyday life is like; how masters talk, walk and work; what the learners do). Brown and Duguid (1991) emphasize that knowledge is produced in improvised and unfolding practices. They argue that the central processes of knowledge production consist of narration, collaboration, and social construction. They use the example of Orr's repairmen to illustrate how problems can be solved via story-telling. The stories not only contain the factual details of repairmen's experiences, but also engender an interplay between their experiences, memories, and the machines' reactions, which ultimately leads to insights regarding diagnosis and repair. This process gradually establishes new knowledge of how to repair Xerox machines. Given the importance of shared narratives, another feature of communities of practice is collaboration. The insights gained via practices are not privately owned but are collaboratively constructed. The participants in practices provide one another social "affordances" (Cook and Brown, 1999). For example, when repairmen come across difficulties, they like to work together and discuss the problems in groups. This leads to the third feature of practice discussed by Brown and Duguid (1991), social construction, demonstrated by the fact that the problems the repairmen faced were not those expected by the trainer or included in training documents. The repairmen constructed "a shared understanding" of the machine through their discussion and their interaction with the machines. Given this, we can claim that narratives only build knowledge when collectively articulated and socially distributed.

After knowledge is produced in CoPs or NoPs, however, how is it maintained? For Lave and Wenger (1991), the community members' routine practices not only create, but also maintain knowledge. The process of legitimate peripheral participation enables the newcomers to learn from the old timers and habituate themselves to local modes of behavior. Consequently, the practices of communities are reproduced. Although Brown and Duguid (1991, 2001) emphasize the improvised process of knowledge production in NoPs, they do not reject the forces of knowledge reproduction. They argue that the community members' interaction not only produce new knowledge, but also maintain and reproduce existing distributed knowledge. For example, the Xerox repairmen's recounted stories later become a shared repertoire of the community and part of the communal knowledge.

What becomes of this knowledge, and how do community members access it? Though Lave and Wenger (1991) and Brown and Duguid (1991, 2001) emphasize different aspects of how knowledge is produced and maintained in a CoP or NoP, they both confirm that knowledge is created and maintained in daily practices. Thus, successful access to the knowledge depends on the "transparency" of the activities, processes, and artifacts in a CoP or NoP.

Since CoPs and NoPs inevitably involve interactions among community members, Lave and Wenger (1991) and Brown and Duguid (1991, 2001) also discuss important relational aspects defining the accessibility of communal knowledge. In a CoP described by Lave and Wenger, apprentices' successful learning is premised on "legitimacy" to participate in communities of practices, usually granted by the masters. To gain legitimacy, apprentices begin with jobs that are of less important to the community. Social structure and the old timers' view of the newcomers (as novices "who should be instructed" or peripheral participants) influence whether the newcomers can be granted "legitimacy." For example, Lave and Wenger (1991) quote the example of how the physical layout of the work setting denied apprentice butchers' access to the practices of the experienced journeymen. Some meat departments were laid out in the way that the apprentices working at the wrapping machine could not observe how the journeymen cut and saw meat. Lave and Wenger (1991) also offered an example of how the practices of butchers' trade school classes, such as the employment of workbooks and examinations are separated from real practices, and thus cannot assist effective learning. Because their empirical studies have focused on communities of apprenticeship (e.g., Vai and Golan tailors in Liberia, Mayan midwives in the Yucatan, U.S. navy quartermasters, non-drinking alcoholics, and U.S. supermarket meat cutters), the social structure and power relations that characterize learning dynamics concentrate on the relationship between old-timers and newcomers.

In contrast to Lave and Wenger (1991), Brown and Duguid (1991, 2001) emphasize the lateral interactions among participants in NoPs. Since knowledge is collectively created and owned by participants' mutual engagement, it is significant for the participants to access each other. Brown and Duguid (1991, 2001) focus on the tension between management and communities of practice and how formal management stifles communities of practices, and thus denies community members access to each other. However, they fail to account for lateral relations among people engaging in these practices. We are left with the cozy picture that these repairmen are willing to share what they know in every situation, but we are not informed about the potential conflicts among them, which might affect their participation in CoPs and NoPs.

Duguid's (1991) and Wenger's (1999) discussions imply that the primary processes of communities of practice involve members' frequent interactions, through which they share experiences and recount stories. Thus, facilitating communities of practice requires the creation of opportunities for interactions among members, and that the quality of interaction is improved.

As discussed in the last section, although the literature of CoPs and NoPs emphasizes the importance of members' participating in practices and the significance of fostering collaboration, this literature does not systematically discuss the barriers that community members face when attempting to participate in collaboratively and socially constructed practices. In this section, I will review literature related to remote collaboration to define the factors that affect distributed collaboration, specifically, remote collaboration in scientific communities as distinguished from the business settings much of the literature discusses.

Nardi (2005) and Nardi and Whittaker (2002) suggest a framework to understand the processes of interpersonal communication. They point out that most studies of computer-mediated communication (CMC) focus on how well information technology supports the transfer of messages, however these studies neglect the process of building those relations that define "communicative readiness." They argue that interpersonal communication consists of two processes: (1) building fields of connection, and (2) information exchange. A field of connection refers to the social conditions which ready people to be involved in information exchange. In the process of information exchange, people disseminate information to and receive information from their conversation partners. Inspired by this framework, we can consider community members' interactions in a CoPs and NoPs are constituted by two processes: (1) building fields of connection, which enables community members to access and gain attention from each other; (2) transferring knowledge and practice, which enables community members to learn through practices.

Building Fields of Connection

Drawing on empirical studies of instant messaging, face-to-face communication and other related literature, Nardi (2005) defines three dimensions of fields of connection: social bonding (affinity), expression of commitment, and capturing and monitoring attention. Social bonding refers to a feeling of connection between people, that is, "an openness to interacting with another person," expression of commitment denotes people's engagement in ongoing communication for projects of mutual interest; capturing and monitoring attention refers the process through which people try to gain and maintain attention from their communication partners. While all of these elements refer to interpersonal communication between individuals, they are applicable to a more general collaborative structure of interaction.

Prior research has defined many social, organizational and technical factors that facilitate the process of building and maintaining fields of connection and information exchange, each of which is discussed below.

Establishing and maintaining social bonds. Systems supporting interpersonal interactions should help increase the opportunities for people to meet and connect with suitable partners—people who share common research interests or work on similar projects. One way to increase such opportunities is to physically concentrate suitable partners (Robert. Kraut, Fish, Root, & Chalfonte, 1990). A research organization accomplishes the concentration of suitable partners by placing people working on the same project or sharing similar research interests close to each other. A virtual organization such as a collaboratory can virtually concentrate scientists who share similar research interests or work on similar projects from all over the world. It may help scientists stay informed about who is doing similar research and with whom they can communicate and collaborate. Collaboratories may create opportunities for scientists to connect with researchers from other institutions and other countries.

When a pool of potential suitable partners is available, it is important that there exists an "environmental mechanism" that brings people together. In organizations, this mechanism can be a hallway, a cafeteria, coffee lounge or other place where people can meet and start spontaneous conversations (Robert. Kraut et al., 1990). In a virtual organization, such as a collaboratory, instant messenger can help build a space for scientists' chance encounters; email listservs and web forums create a space for "asynchronous meeting"—researchers do not come to the space at the same time, but they can still disseminate to and obtain information from others.

However, in a virtual setting, geographic dispersion may reduce opportunities for people to interact. Geographical distance reduces frequency of spontaneous communication (Burke, Aytes, Chidambaram, & Johnson, 1999; Dennis, 1996; Saunders, Van Slyke, & Vogel, 2004), and time differences decrease the opportunities for real-time problem solving (Grinter, Herbsleb, & Perry, 1999; Herbsleb, Mockus, & Finholt, 2000; Malone & Crowston, 1994).

Gaining commitment and attention. Opportunities for researchers to reach suitable partners do not guarantee that others will pay attention to them. There also need to be mechanisms enabling researchers to obtain other people's commitment and attention to a project in which they are interested. Research institutions and scientific communities help researchers gain other people's commitment and attention in several ways:

First, people need to establish social bonds which enable them to gain commitment and attention from each other. Social bonding is achieved through social activities, such as touch, eating and drinking, sharing experience in a common space, and informal conversation (Nardi, 2005). People establish social bonds with each other through hugs, handshakes, etc. In computer mediated communication, where people cannot see each other face-to-face, they also use language to attempt to portray a sense of touch to increase affinity. For example, they might say in their instant messaging, "hugs." People also deepen social bonds through eating and drinking together. "Sharing food and drinking are intense bodily activities that stimulate intense social responses, summoning feelings of connection at a deeper, pre-conscious level" (p105). Researchers have found that eating and drinking can also occur in virtual settings. For example, people talk about what they are eating at the keyboard so that they feel bonded through eating. Another means of social bonding is sharing experiences in a common physical space. In other words, it is important for people to gain a sense of "physical connection in context." People become more familiar with their collaborators through the shared experience of attending conferences or industry events. In comparison with listening to reports from their remote collaborators through phone calls, people gain much more information about their collaborators through site visits, which offer them opportunities to access the latest gossip and updates face-to-face. In computer mediated situation, people tend to use language to evoke a sense of space. Informal communication also helps people to build social bonds through greetings, jokes, gossip, etc. These various forms of informal conversation allow people to relax and connect with each other more easily.

Second, the mere physical presence of another person creates an obligation to engage conversation partners (Kiesler & Cummings, 2002; Robert Kraut, Egido, & Galegher, 1988). In addition, in an organizational setting, frequent encounters improve individuals' feelings of familiarity with one another, and consequently increase the frequency and desire of contact among colleagues (Kiesler & Cummings, 2002). However, in a virtual organization, such as a collaboratory, where members are geographically dispersed, "the lack of real and perceived presence of others and lack of shared social settings" hinders communication. They are not in as frequent contact with their coworkers (Kiesler & Cummings, 2002). Empirical studies also show that people communicate most often with those who are physically close (Allen, 1977; 1990). In Allen's data, about 25% of engineers whose offices were next door to each other (less than 5 meters apart) discussed technical topics at least once a week; if their offices were 10 meters apart, this figure dropped below 10%.

Third, group identity motivates people to communicate with and help their group members. Constant et al. (1996) find that in a global computer manufacturer, information seekers receive help from information providers even though they lack personal connections with each other. They suggest that people help one another on the computer network, because they belong to the same organization and because they are concerned with offering help to solve organizational problems. However, participants in a collaboratory usually come from different organizations. Their multi-membership status affects their participation in a single community. For example, scientists who collaborate with the members of other organizations have to shoulder multiple tasks—tasks from their own organizations and tasks from collaborative work. They may encounter time conflicts. In addition, the goals of the subgroups who participate in a collaboration might conflict. For example, in collaborations where domain scientists (e.g., physics, biochemistry, etc.) and computer scientists work together to develop scientific software supporting collaborative work, the domain scientists seek from the collaboration a functional and efficient research tool, while the computer scientists regard the computer system as an object of research, and wish to experiment and make innovations in the software (J. S. Olson et al., 2008).

Fourth, dependencies among the different entities in a community define their mutual engagement. When people engaging in a community of practice recognize that others have reciprocally needed skills or resources, they tend to be more engaged in collaborations (J. S. Olson et al., 2008). Dependency relationships also affect how different members access resources in a community. As discussed in the previous section, in an apprenticeship type of practice, the newcomers rely entirely on the masters' granting of access to them and the resources in the community (Osterlund & Carlie, 2005).

Finally, status differences affect people's participation in CoPs or NoPs. Status differences influence how much attention people pay to their communication partners. When groups make decisions, high-status group members often dominate discussion and are more influential in decision making. The problem here is that a person's status in a group often does not derive from his or her specific skills and abilities, but from less relevant physical and social cues such as race, gender, age, or social standing (Weisband, Schneider, & Connolly, 1995).

In addition, status differences determine people's access to informal channels of communication. For example, in scientific communities, researchers communicate with colleagues outside their affiliated institutions through a network of practice called invisible colleges. An invisible college consists of around 100 elite researchers who regularly exchange information or preprints of papers about the newest research progress (Price, 1971). These colleges often arise around the nuclei of major researchers in different fields. Thus, there exists a status hierarchy in an invisible college, which directly affects scientists' opportunities to access communication channels. Those at the center of invisible colleges can gain the most attention and have the most opportunities for informal communication. Peripheral researchers, such as scientists from developing countries, who cannot have access to and obtain attention from any member of the invisible colleges, have few opportunities for informal communication.

Learning and Knowledge Transfer in Communities of Practice and Networks of Practice

Nardi (2005) and Nardi and Whittaker (2002) point out that in addition to building and sustaining the field of connections, another important process of communication is the exchange of information. Similarly, in communities of practice and networks of practice, in addition to building relationships among community members, another significant process is for community members to exchange conceptual and procedural knowledge and learning from each other.

The literature tends to classify knowledge into explicit knowledge and tacit knowledge. Explicit knowledge is also referred as objective knowledge, articulated knowledge (Hedlund, 1994), articulable knowledge (Winter, 1987), verbal knowledge (Corsini, 1987), and declarative knowledge (Kogut & Zander, 1992). It refers to knowledge that can be communicated from its possessor to another person in codified forms. It is characterized by two elements: it can be easily "written down, encoded, explained, or understood", and it is not specific or idiosyncratic to the firm or person possessing it, making it easy to be transferred (Ambrosini & Bowman, 2001).

In contrast to explicit knowledge, tacit knowledge is difficult to articulate; as argued by Polanyi (1966), "we can know more than we can tell." The distinction of tacit and explicit knowledge echoes the difference between "know *how*" and "know *that*" (Brown & Duguid, 2001). "Knowing *that*" alone cannot inform people of how to make use of knowledge. To apply "know *that*" in a useful way requires the acquisition of “know *how*”, which is similar to Polanyi’s tacit dimension of knowledge. If we say “know *that*” circulates as precepts and rules, “know *how*” can only be learned through practice.

What makes “know *how*” difficult to circulate is that much of the practice through which learning *how* occurs is local. Brown and Duguid (2001) argue that knowledge transfer from one community to another involves the processes of “disembedding” and “reembedding” knowledge. Different communities have different practices, which build different embedding environments. Knowledge is disembedded in one place to be reembedded in another. The more that embedding conditions are similar, the more likely knowledge transfer is likely to be more successful.

Community differences sometimes result from disciplinary boundaries (Bechy, 2003; Brown & Duguid, 1991; Wenger, 1999). Communities of practices where people have different jobs or occupations speak different languages and have different loci of practice, resulting in different understanding of even the same practice by members from different communities. For example, Bechky (2003) demonstrates that the misunderstanding between engineers, technicians, and assemblers on a production floor is related to their work contexts. The engineers design and create drawings for others to use, and thus their conceptualization of the product and the production process is filtered through the lens of drawing. By contrast, the assemblers work with the machine in a hands-on manner, building parts and installing them on a frame to build the finished product. Thus, the engineers’ perception of the production process is based on their hands-on experiences. The technicians perform the role of empirical interface between engineering and manufacturing, taking the engineers’ conceptual representations and building concrete machines. Thus the locus of their practice is both conceptual and physical. Because of their different work contexts and the loci of their practice, they talk about the same object in different ways.

Community differences arise also from geographical boundaries. People from the same locale or site share site-specific knowledge and practices transcending both role and task boundaries (Bechy, 2003; Hildreth, 2000; Sole & Edmondson, 2002). Through participating in particular site practices, members mutually influence their interpretations and understanding of what is distinctive, important, and lasting about the site, resulting in identities and norms of participation associated with physical sites. When working at the same site, there are more frequent opportunities for informal interaction, enabling a shared history of experiences and development of transactive memory, that is, the awareness of colleagues' expertise and competence. Transactive memory is more difficult to access outside the site boundaries, because distance interactions tend to be less frequent, leading to insufficient site-specific practices. In addition, people's preferred problem-solving approach are constrained by their local assumptions and resources. Thus, even though when they can access other sites' facilities, tools and technologies, it is difficult for them to obtain a full understanding of these resources and take full advantage of implementing them.

Community differences can also arise at organizational boundaries. Organizational boundaries sometimes overlap with geographical boundaries, because different organizations tend to be geographically dispersed. Thus, we can see shared identities and norms of participation connected with affiliation to organizations. We can also see shared history of experiences and transactive memory within an organization. And these norms, history of experiences, and transactive memory are organizationally bounded, and difficult to comprehend or access for people from other organizations. Understanding the difficulty to transfer knowledge, researchers propose ways to facilitate knowledge sharing across communities of practice. Moreover, organizational differences arise from organizational structure, the institutional rules, and different technology infrastructure. For example, Lam (1997) describes an inter-organizational collaboration between one firm from the UK and one from Japan. These firms are reported to be characterized by completely different organizational structures, processes and routines. The Japanese side tends to get everybody involved, but the UK side does not. Before the Japanese side commits to anything, they need to get all the relevant groups involved. The UK side complains that they are very frustrated by the fact that they need to discuss with all the groups about every decision they make.

Different technology infrastructure in different communities also affects the way scientists interact, learn from each other and transfer knowledge from one site to another. Instrument sharing involves remote control of the instrument and real-time conversation between collaborators, which require scientists to have advanced computer systems and network infrastructure. Data sharing calls for great computer capacity to process large quantities of data, and sometimes requires scientists to have the resources to access databases that require a fee. However, there exists a digital divide in Internet use caused by inequality in access to the Internet. DiMaggio and Hargittai (2001) argue that greater benefits from Internet use will accrue to people with high social economic status, whose resources empower them to adopt the Internet sooner and more productively than their less well-off neighbors. An example of the digital divide in the scientific community can be seen from a 2003 report on geographic issues of network access (Williams *et al.*, 2003). This report compared figures for three groups of countries in Europe: (1) the European Economic Area (2) the ten countries that will have joined the European Union in May 2004, (3) and a number of other countries neighboring the European Union. On average the typical core capacity of the national research network is five times smaller in the second group of countries than in the first group, while it is 25 times smaller in the third group of countries. The consequences of this digital divide might be serious, especially in an age when the international research community is moving rapidly to adopt various forms of collaborative e-science. It implies that in the future only those researchers who have access to a high-capacity research network will be able to take part. The countries without an adequate research network will suffer from "research exclusion."

Brown and Duguid (1998) discuss the importance of engaging both knowledge brokers, who can introduce elements of one community of practice to another, and translators, who are not members of any single community, but able to frame the interests of one community in terms of another community's perspective. Wenger (1999) suggests developing boundary practices, where delegates from different communities engage with each other. Boundary practices are a form of collective brokering. A range of studies have highlighted the importance of boundary objects (Brown & Duguid, 1998; Carlie, 1998; Star & Griesemer, 1989; Wenger, 1999). Boundary objects are of interest to each community involved but seen or used differently by each of them. They can be physical objects, technologies or techniques shared by different communities. Boundary objects allow a community to distinguish itself from other communities, making its own presuppositions and its attitudes towards other communities more apparent to itself. Cross-community forums offer another platform for knowledge transfer (Boland & Tenkasi, 1995).

Other researchers discuss the importance of creating and sustaining common ground for knowledge transfer. Common ground refers to "knowledge that the participants have in common, and they are aware that they have it in common" (Clark & Brennan, 1991; G. M. Olson & Olson, 2000). Common ground is established both through cultural and social knowledge embedded in a social and organizational setting, and also through situational knowledge such as individuals' gestures and behavior in conversations. When working in the same organization, people usually share the same social and organizational culture, which helps them to gain the knowledge of who is expert in which field, and from whom they can seek help. Thus, it is easier for researchers working in the same institution to identify appropriate partners with whom they can discuss their research questions. Sharing more immediate situational knowledge provides participants in interpersonal interactions with an understanding of their partners' mental and behavioral states, allowing them to make decisions of when to introduce a difficult topic. Also, people need to know the object their partners are talking about during a conversation. The informal interaction within an organization is often face-to-face communication, where various visual cues help people to establish and maintain common ground. For instance, people can look at the conversation initiator as a cue for making an utterance (Clark & Brennan, 1991).

Bechky (2003) argues that when different communities are involved, it is important for people to co-create some common ground. He suggests that people from different communities have different knowledge, which results from key differences in work contexts—language, locus practice, and the conceptualization of the product and production process. In order to create common ground, knowledge of people from different communities should be transformed. The transformation process is usually performed through "tangible definitions," that is, examples that can physically display the reasons for misunderstanding between people from different communities. A tangible definition works as visible and manipulable representations, allowing people from different communities to ground their divergent understandings in the physical world. It helps people to recontextulize physical work contexts, enabling them to see key differences in the work context. Bechky (2003) describes how an assembler helps an engineer to solve the chip problem he comes across. The assembler has a spatio-temporal, procedural understanding of the machine; that is, he understands which part should fit where and in what order they should be assembled. The engineer, however, has a conceptual understanding of how the parts should be assembled, but cannot understand the assembler's description. The assembler then gives a physical demonstration of the process by which the machine is built. The demonstration recontextualizes the assemblers' work context, enabling the engineer to better understand the assembling process and be better informed about how to address the chip problem through his design.

Sole and Edmondson (2002) suggest that in order to build common ground among geographically distributed communities, it is helpful for community members to be exposed to the practices and resources of other sites. This kind of exposure allows visitors to understand the social contexts of site-specific practices, build shared experience history with local members, and obtain a better understanding of the physical resources of the local sites. Sole and Edmonson's (2002) argument echoes Brown and Duguid's (2001) suggestion that "learning is fostered by fostering access to and membership of the target community-of-practice."

However, Osterlund and Carlisle (2005) critique the literature of learning and knowledge transfer for missing the relational perspective of communities of practice and networks of practice. That is, given the positive effects of translators, boundary brokers, boundary objects in negotiating the differences among communities, we do not yet know "the concrete dependencies that drive these negotiations and the stakes that organization members bring forth when engaging in such boundary practices" (p103). Neither do we understand the power relationship among communities and how this relationship would affect cross-communal learning and knowledge exchange. For example, when knowledge is mainly transferred from Site A to Site B, what would motivate Site A to do so?

Orlikowski (2002)points out that literature about knowledge transfer across communities has treated knowledge as a thing that can be captured, stored, transmitted. Thus, scholars often talk about transferring "best practices." This literature, however, neglects the fact that knowledge and practice is reciprocally constitutive. "Best practices" are not concrete objects, but they are enacted by the particular local practices. Therefore, sharing know *how* should not be viewed as a process of knowledge transfer, involving the process of embedding it at the resource site and disembedding it at the target site. Sharing know *how* can be seen as a process of enabling others to learn the practice that entails the know *how*. It should be a process which helps others develop the competence to enact—in a variety of contexts and conditions—the "knowing in practice."

SCIENTISTS IN DEVELOPING COUNTRIES

Much like scientists who work in non-prestigious universities in the US, scientists in developing countries do not have many opportunities to engage in informal collegial communication. Neither do they have as many resources as scientists in research universities in the US.

Thus, scientists from developing countries have been seen as isolated on both informational and interpersonal dimensions (Davidson, Sooryamoorthy, & Shrum, 2002). It has been observed that the opportunities for scientists from developing countries to access timely scientific information are seriously limited. Journals, books, newsletters, preprints, and manuscripts of unpublished work: these are essential sources for active researchers to gain timely information. Acquisition costs, as well as inadequate libraries and documentation centers, prevent most scientists in developing countries from accessing these resources.

Scientists in developing countries are also isolated interpersonally. They usually have smaller research communities, which tend to be dispersed over wide areas. When separated geographically, infrastructure problems with transportation and communication hinder scientists in the developing areas from engaging in regular collegial communication and thus benefiting from the intellectual stimulation that contact brings.

Although these observations may be accurate as far as they go, evidence based on empirical studies of scientists in developing countries remains extremely limited. The most frequently cited study is Gaillard (1991)'s study. Gaillard surveyed 489 scientists who received grants from the International Foundation for Science between 1974 and 1984. He found that scientists in developing countries communicate as infrequently with scientists in their own countries as with scientists in developed countries. They tend to interact only with colleagues in the same institute or more often, in the same department or research unit. However, methodological problems in Gaillard's study make it difficult to gain a complete understanding of the scientific communities in developing countries. The research results are based on reported frequency of communication. It is difficult to discern the whole context, such as why they communicate with other scientists, and what are their communication channels, and possible barriers to communication.

A clear inequality in resources between scientists in developing and developed countries is also reported. Developing countries, for example, generally spend much less than one percent of their gross domestic product on scientific research, whereas rich countries devote between two and three percent (UNESCO, 2005). Gaillard (1991)'s study also showed that few laboratories in the developing countries have both modern, reliable equipment and the skilled permanent personnel required to operate and maintain it.

Attention has also been directed to the influence of science from the developed world on the developing countries. Bassala (1967) proposes a three-phase model to account for the global diffusion of science. In the first phase, "the European who visits the new land, surveys and collects its flora and fauna, studies its physical features, and then takes the results of his work back to Europe" (p611). The second phase, i.e., colonial science, is marked by "dependent science." At this stage, a broader range of scientific topics are studied, and "colonial scientists" begin to take the place of dilettante collectors to conduct research. “Colonial scientists” are either “native or transplanted European” colonists or settlers, who either receive formal education in a European institution or are informally trained through studying the works of European scientists, purchasing books, laboratory equipment, and scientific instruments from European suppliers. Colonial scientists’ research interests tend to be directed by problems raised by European scientists. Because of the inadequacy of scientific education, scientific organizations and journals, colonial scientists seek membership in and honors of European scientific societies, and publish their work in European scientific journals. The third and final phase is reached when scientists gain “independent scientific traditions.” That is, they are not only able to receive adequate training, institutional support, and intellectual stimulation from their home countries, but also enjoy better opportunities to pursue a new research direction and open new fields of scientific research.

Basalla’s diffusion model has been critiqued by other researchers: First, it misleadingly suggests that scientific exchange flows one way, from Europe to the colonies, paying little attention to the crucial return of people, information, artifacts and specimens, which play important roles in reconstructing European science. Second, the model is based on an unproved assumption that western science represents authoritative knowledge. Finally, the diffusion model neglects the relationship between colonial science and “other mechanism of colonial power” (Jackson, 2003).

Researchers have also studied the impact of collaboration on scientists from developing countries, both in general and as enabled by information. Duque and Ynalves et al (2005) study the relationship between collaboration and scientists’ self-reported productivity in developing areas (Ghana, Kenya, and the State of Kerala in south-western India). They find that in general, collaboration is not associated with an increase in scientific productivity. Their finding contrasts to the similar studies conducted in the developed world, which contend that collaboration is positively related to productivity

(Lee & Bozeman, 2005; Walsh & Maloney, 2003). They also find that although the access to email helps attenuate research problems, difficulties in research are defined more by national and regional contexts than by the collaboration process itself. They suggest that benefits brought about by information technology might be attenuated by the local conditions, which unsettle the relationship between collaboration and scientific productivity. However, they did not study how the national and local contexts interact with information technology use. Similar to other research on relationship between the use of information technology and scientific productivity, their sole focus on email constitutes another limitation to their study.

Shrum (2005) explores the role of the Internet in changing the relationship between scientists from developed and developing countries. He argues that before the advent of the Internet, the relationship between scientists from developed and developing countries could be characterized by a "donor-recipient" relationship; thus scientists from the developed world look like "guests" for those from developing countries. Funding agencies make investments on plans of development they wish to see in the developing world, although the investments may or may not effect development in the way expected. As "guests," scientists from the developed world tend to be temporarily involved in various projects, because the resources provided by the donors are only available within a limited time frame. Shrum argues that the Internet might create a better opportunity for an egalitarian collaboration between the developed and the developing areas, because it may enable scientists to keep long-term interactions. However, Shrum also raised the critical question that it is unclear to what extent the Internet can change the relationship from one "in which embedded guests propel initiatives into distant lands to one in which colleagues collaborate as intellectual equals from distant locations." If we recount this question in terms of diffusion model, it should be that we do not know that the Internet can be the power to propel science in developing countries to change from "dependent" to "independent" science.

CONCEPTUAL FRAMEWORK AND RESEARCH QUESTION

As discussed above, scientists' productivity is positively correlated with what the working environments can afford them, that is, resources and communities of practice. Thus, in order to understand the impact of collaboratories on scientists from developing countries, it is important to understand how a collaboratory changes the environmental factors affecting scientists' performance.

Since the discussion of how organizations support scientists to reach resources remains relatively intuitive, my literature review has focused on how communities of and networks of practice are supported in scientific communities. Communities of practice and networks of practice provide an explanation of how scientists learn from and share knowledge, especially tacit knowledge, with each other. The major processes of communities of practice and networks of practice involve building fields of connection and transferring practices and knowledge within and among communities. Prior literature has identified socio-technical factors affecting these processes, as shown in Figure 2. It is also found that in a virtual organization, such as a collaboratory, the fact that the members belonging to organizations, which are geographically dispersed, perform different routines and practices, and have different institutional rules and organizational culture, will affect individuals' participation in collaboratories.

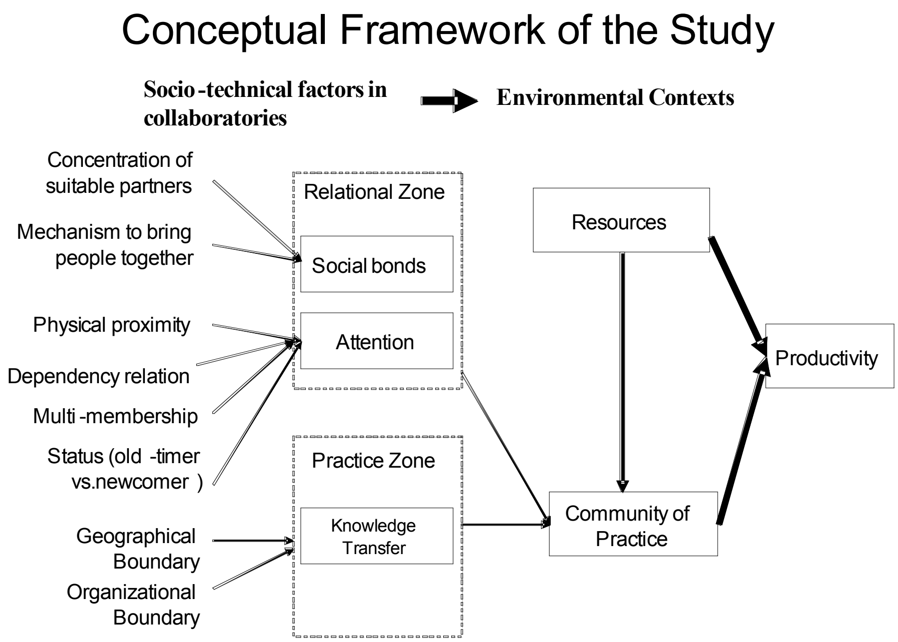

Figure 2 Conceptual Framework of the Study

In this study, a collaboratory has a community component consisting of various communities of practice and networks of practice. Members of collaboratories participate in practices in their local academic communities, and at the same time, in various communities of practice and networks of practice with collaboratory members from other organizations. It is also notable that in different communities of practice, there exist different levels of peripherality. In a local organization, senior scientists tend to be the old-timers of the community of practice, while junior scientists participate at the periphery where they interact with senior scientists and junior colleagues. In a collaboratoy as a whole, some organizations are newcomers and members from these organizations are regarded as peripheral participants. For example, in some collaboratory projects, developing countries may be participating for the first time, and are therefore the newcomers. The newcomer organizations tend to have poorer infrastructure and less experience. In a virtual organization, such as a collaboratory, peripherality of members not only results from participants' experiences as discussed earlier, but also from geography. For example, this can occur when most of the collaboratory members are located in the US and Europe, and only some participant labs are in developing countries far away from US and Europe. Those in developing countries may find themselves unable to participate in communities of practice as actively as those located in the US or Europe.

Given our understanding of the mechanism of how community members build relationship, engage each other, and transfer practices and knowledge in communities of practice and networks of practice, the study intends to understand:

- To the extent that inequality in resources in participant institutions, geographic dispersion, cultural difference, and use of information technologies affect communities of practice and networks of practice, what are the effects of collaboratories on scientists from developing countries?
  - In what ways do collaboratories benefit scientists from developing countries?
  - How do collaboratories facilitate scientists in developing countries to access resources?
  - How do collaboratories facilitate scientists in developing countries to build fields of connection with their collaborators?
  - How do collaboratories enable knowledge and practice transfer between scientists from developed and developing countries?
- What are the social, technical, cultural, and political obstacles that hinder scientists in developing countries from benefiting from collaboratories?
  - What are the barriers for scientists in developing countries to access resources?

- What are the barriers for scientists in developing countries to build fields of connection with their collaborators?
- What are the barriers for knowledge and practice between scientists from developed and developing countries?

SUMMARY

This chapter has first reviewed the literature on the sociology of science suggesting that resources and communities of practice provided by organizations influence scientists' performance. A literature review of CSCW, organizational studies and communities of practice has also revealed socio-technical factors affecting communities of practice. This lays a foundation for the examination of how these factors may play out in collaboratories, and how these might differ for scientists from developed and developing countries. At the end of this chapter, I present a conceptual framework and raise research questions for the study.

CHAPTER 3

RESEARCH METHODS

ASSUMPTIONS AND RATIONALE FOR A QUALITATIVE STUDY

I adopted a qualitative research method, primarily interviews complemented by field observation, for this study for several reasons. First, qualitative approaches focus on ordinary events that occur in natural settings (Crestwell, 2007; Miles & Huberman, 1994), and enable researchers to capture the contexts and settings that shape a phenomenon. Adopting a qualitative approach allowed me to understand the social contexts in which various information technologies are adopted, and thus empowered me to discern socio-technical factors that affect scientists' use of technologies in collaboratories. Secondly, qualitative data, which are usually collected over a sustained period of time, allow researchers to feel confident that they understand these processes in details (Creswell, 1994). The stories shared by the participants in interviews and observation of scientists' daily work enabled me to understand the process of how scientists communicate and share resources with collaboratory members. Thirdly, a qualitative approach is conducted when we need to explore problems or issues of a group or population whose voices are silenced (Crestwell, 2007). Compared to our understanding of scientists from developed world, little is known about scientific communities in developing countries. The inductive nature of the qualitative approach allows categories to emerge, which enables the researcher to identify patterns and develop theories to understand or explain a phenomenon, such as in the case of this study, collaboratory use by scientists from developing countries.

It is notable that among qualitative researchers, a spectrum of divergent opinions exists regarding research design and data collection. Many social anthropologists and social phenomenologists advocate keeping pre-structured designs to a minimum. They argue that social processes are so “complex,” “relative,” “elusive,” or “exotic” that they cannot be studied through explicit conceptual frameworks and standard instruments. Instead, they advocate that a conceptual framework and meaningful research questions should emerge from field study; even the setting and participants for the study should not be selected before fieldwork (Miles and Huberman, 1994). Other researchers argue for a more bounded research design. Miles and Huberman (1994) argue that data collection is unavoidably selective, because researchers all come to fieldwork with orienting ideas. This can be exemplified by the fact that a sociologist and psychologist would obtain different data even though they observe the same phenomena. Thus, Miles and Huberman (1994) suggest a more structured design.

I adopted Miles and Huberman’s (1994) approach, which argues that a more structured design is especially useful to those researchers who understand the phenomenon conceptually, but also know that parts of the phenomenon need to be more fully understood. A more structured design is also helpful for those researchers who are able to identify suitable locations and subjects for the study. In my study, prior literature contributed to my conceptual understanding of scientific collaboration. I also knew that the subjects of the study should be participants of collaboratories. However, it was unclear about how scientists from developing countries collaborate with scientists from developed countries in collaboratories. Thus, a more structured design, that is, to adopt a conceptual framework derived from previous literature as the starting point, was more suitable to my study. Miles and Huberman (1994) also point out that a more structured design should be adopted when the research involves multiple cases in order to obtain comparability across cases. In my study, I needed to study seven collaboratories. If I did not have a common framework or instrumentation, it would have been difficult to compare different collaboratories. Furthermore, a structured design can help researchers be more focused, and avoid the problem of seeing everything as important in their fieldwork. A more structured design also enables researchers to discern details, complexities and subtleties that may otherwise be neglected. Thus, more structured designs particularly suit less experienced researchers, who tend to lose their focus more easily.

Although my study was guided primarily by suggestions made by Miles and Huberman (1994), this still leaves out room for an inductive approach. The conceptual framework was not only derived from prior literature. Since little is known about scientists from developing countries, I initially conducted 20 pilot interviews. In these interviews, I asked scientists general questions about their working processes, the ways in which they benefit from collaboratories, and any barriers to participating in collaboratories. These pilot interviews indicated what research questions I should focus on, as well as the theoretical conceptual framework likely to be most useful. Although knowledge about collaboratory use is limited, my pilot interviews suggested that in addition to sociology of science and computer supported cooperative work, literature on organization studies and communities of practice and networks of practice provided a frame for my study, aiding me to decide who and what to examine[2]. However, the data analysis was not constrained by the conceptual framework. considering the existing research questions open the possibility that new ones would emerge.

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[2] Luo and Olson (2008)and Luo (2006) reported the results of the pilot studies.

DATA COLLECTION METHOD

Semi-structured interviews complemented by field observation comprise the primary data collection methods of the study. The interview protocol includes open-ended questions, which were built upon literature review and research questions (see Appendices 3 and 4). The interviews aim to collect data on collaboratory members' perceptions of whether collaboratories enable or hinder them to access resources and participate in communities of practices and networks of practice, and the social and technical factors that contribute to those effects. I interviewed 67 people from June, 2005 to December, 2006. Generally, the interviews lasted from forty minutes to two hours. Some participants were interviewed twice and at different times so that I could monitor changes in collaboratories over time. Some scientists were contacted twice or three times after I interviewed them to clarify information they told me. Most interviews were conducted in the labs where scientists worked. When this was not possible, I interviewed them by phone. All the interviews were digitally audio recorded with the consent of participants.

Collecting data via semi-structured interviews has strengths and weaknesses. Some advantages are that they allow researchers to control the questions they ask, and to collect data about past events and about informants who cannot be observed directly (Weisss, 1994). Since it was not feasible for me to observe every scientist or the entirety of their communication and collaboration with other members of the collaboratories, I relied on scientists' accounts of their experiences of participating in collaboratories.

A notable weakness of collecting data via interviews is that the information is filtered through the views of interviewees in a designated place and at a specific time, and in fact is vulnerable to errors caused by both respondents and interviewers. The respondent may embellish a response; try to give "socially desirable" answers to please the interviewer; or omit or alter relevant information, either due to poor memory, or intentionally to prevent the interviewer from learning something about the respondent. Similarly, the interviewer's personal characteristics or questioning techniques may hinder proper communication of the questions (Fontana & Frey, 2000). Weiss (1994) suggests that we can check on the validity of a respondent's response by interviewing other respondents. I adopted his advice by interviewing a variety of respondents doing similar work; for example, after interviewing scientists from developing countries, I interviewed and obtained the perspectives of their collaborators in developed countries. Taylor and Bogdan (1998) suggest that the weaknesses of interviewing can be overcome by getting to know people well enough to know what they mean, by creating an atmosphere in which respondents feel comfortable enough to talk freely, and by spending time with people. I followed these suggestions and familiarized myself with the scientists and the subjects they studied by reading respondents' biographical information and by reading online documents and other materials pertinent to the collaboratories prior interviewing the scientists. I also attempted to establish rapport with respondents by introductory contact, by visiting scientists in person, and by interviewing scientists in their native languages.

Field observations also help moderate the limitations of interviews. In the summer of 2005, I visited three Chinese labs, staying at each for one week. In the summer of 2006, I revisited those labs and stayed again for one week. In the summers of 2005 of 2006, I also visited two Korean labs and stayed in each lab for two days. In July 2006, I stayed in Institute X in Europe, which houses detectors and gathers high energy physicists from all over the world, for three weeks. I revisited this lab in December 2006 and stayed for a week. During my visits, I observed scientists in their everyday work, as well as during meetings, teleconferences and video conferences. I also observed scientists' informal communication during coffee breaks and at lunch and dinner time. In the fall of 2006, I observed scientists from University M as they participated in monthly videoconference with scientists from other US scientists who participated in one of the collaboratories of high energy physics. Although interviews are the major method for data collection, field observations ground the interviews in individual contexts and allow me to deepen my understanding of scientists' working process and communication behavior, as well as the communication and research infrastructure of the labs.

In addition to interviewing and observing, I analyzed public documents available on the websites of collaboratory projects, such as annual reports, databases and news articles about the collaboratories. Public documents enable me to understand the historical background of the projects, and help me to gain the language of the participants. In order to understand how scientists communicate online, I also subscribed several group email and observed their communication in online forums.

SETTING

I identified the only seven collaboratories that include participants from developing countries in our database of more than 200 collaboratory projects (see www.scienceofcollaboratories.org). The projects studied are shown in Table 1.

Table 1 Collaboratiories Studied

Collabo-ratory	Field	Distribution of collaborators	Funding	Number of participants interviewed
A	Biomedical science	1 lab in the US and 3 labs in China	common funds available	2 from US and 11 China
B	Biomedical science	30 labs in 6 countries	common funds not available	6 from China
C	Biomedical science	55 labs from 12 countries	common funds not available	4 from Korea, 1US, 2 China
D	Biomedical science	55 labs from 12 countries	common funds not available	1 from US, 1 Korea, 1 Taiwan, 1 South Africa
E	Molecular biology	134 labs in 15 countries	common funds not available	1 from US, 1 Korea, 1 Newzealand
F	High energy physics	161 institutes in 37 countries	common funds not available	6 from US, 6 China, 2 Morocco, 4 Europe
llG	High energy physics	181 institutes in 38 nations	common funds not available	1 from US, 3 Europe, 5 Korea, 7 China

The collaboratories studied vary from each other in terms of their size, geographical dispersion, the nature of collaborative work and collaboration readiness among participants. The nature of collaborative work explains how much collaborators depend on each other for work and resources. When work requires collaborators to be highly dependent on each other to define goals and understand how to do work, the work is tightly coupled. Collaboration readiness describes the extent to which scientists are ready for collaboration. It is determined by scientists' motivation for collaboration and the degree of trust among collaborators, etc. (J. S. Olson et al., 2008). In different collaboratories, scientists from developing countries became involved for various reasons.

In **Collaboratory A**, which is funded by NIH, scientists from three Chinese labs and one US lab collaborate to contribute to the development of specific datasets by studying the immune responses of Chinese individuals infected with non-clade HIV-1. Prior to this collaboratory, the US scientist, Dr. Adams[3], had established successful collaboration with scientists in Africa. Since China is estimated to be one of the regions in the world with the most rapid spread of HIV-1, Dr. Adams was interested in setting up collaboration with Chinese scientists. He initiated proposals to NIH with a few Chinese scientists he knew through various channels. The collaboratory officially began after they obtained funding.

In the collaboratory, the US scientists rely on Chinese scientists to access resources (HIV+ and HIV- human specimen of AIDS patients in China). For data collection, participant Chinese labs also conduct lab experiments, such as performing DNA-based molecular HLA class I and II typing, an array of immunologic assays, and measuring neutralizing antibody responses in HIV-infected people, etc. The US scientists are responsible for transferring basic research techniques and technologies to Chinese scientists. To ensure the quality of data collection, the collaboratory has strict regulations, ranging from the acquisition of blood samples from AIDS patients and the equipment and technologies that may be adopted, as well as the procedures by which experiments should be conducted. The participants hold regular video or teleconferences once or twice a month and an annual conference to share the information about the working progress and future research plans. The US scientists also try to help Chinese scientists to trouble shoot during the regular meetings and annual meetings, and through their site visits to Chinese labs. In terms of equipment, technologies, and experimental procedures, the U.S. scientists are more experienced. For example, in the beginning stages of the collaboratory, though certain equipment and technologies had been adopted for more than ten years by US scientists, they were still new to Chinese scientists. Once

[3] All the names appearing in this dissertation are pseudonyms.

the data collection is completed, both the US and Chinese scientists will be invited to participate in performing theoretical data analysis[4].

Collaboratory B aims to generate an integrative approach that will lead to a comprehensive functional map of the liver. It provides no common funds for its participants. Instead, participants obtain funding from agencies in their own countries. Participants from different countries collaborate to develop standard operating procedures (SOPs) for the collection, preparation, and distribution of liver samples. In this process, scientists from different countries conduct experiments independently on different samples and then compare their experimental results. The collaboratory then distributes the samples. Collaboratory members rely on the collective's experimental results for comparison, evaluation and adoption of a standard data collection. The fact that sometimes one or two sites might fail to provide results does not cause problems, because other sites provide enough data. When a renowned US scientist initiated the collaboratory, he hoped Chinese scientists could participate, because China has many patients suffering from liver diseases. During a workshop, he met Dr. Heng, a memeber of Chinese Academy of Science, and talked about his interests. In 2003, Dr. Heng obtained four million dollars of funding from the Chinese government, and Chinese scientists began to participate in this collaboratory.

Collaboratory C aims to comprehensively analyze plasma and serum protein constituents in humans; to identify biological sources of variation within individuals over time, validated by biomarkers; and to determine the extent of variation across and within populations. The collaboratory creates and distributes specimens to 55 participating labs worldwide. The participant labs conduct experiments on the specimens independently

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[4] When this research was conducted, although scientists also performed some data analyses, their efforts focused on data collection.

and later collectively compare results and decide the standard for data collection through evaluation of technology platforms and specimen handling. Workshops and annual conferences were held to create opportunities for scientists to meet and discuss research. As with Collaboratory B, the results of the research will not be significantly affected if one or two sites fail to provide experimental results. The Korean scientists became involved in the collaboratory, because Dr. Woo, now the Principal Investigator of the Korean lab, was well-known in the field, he knew the initiator of the collaboratory, and he could obtain a large amount of funding from Korean funding agencies.

Funded by NIH, **Collaboratory D**, aims to define the paradigms by which protein-carbohydrate interactions mediate cell communication. Collaboratory D consists of three components: the Steering Committee; the cores, including the Administrative Core and six Scientific Cores; and the participating investigators. The Steering Committee, consisting of 11 members, is responsible for setting the scientific goals and the budget of Collaboratry D, and for ensuring that information and resources generated by the program are efficiently disseminated both within the collaboratory and to the public. The Committee also approves priorities and milestones for each of the Scientific Cores. The Scientific Cores generate material resources, new technologies, and a platform of information that enables progress toward the overall goals. The third component of Collaboratry D are the Participating Investigators, each of whom has a program of funded research within its scope. In return for resources, Participating Investigators agree to accept responsibility for achieving one or more specific aim and to provide the resulting data to the Collaboratry D database. Collaboratry D currently has more than 300 Participating Investigators at more than 170 institutions worldwide. Most of the participating investigators are from developed countries, though some of them are from developing countries, such as Korea, and South Africa. The Participating Investigators became involved in the collaboratory after their proposals were accepted by the steering committee. In the study, I focus on how participating investigators benefit from the collaboratory. Participating investigators work on their own projects, and thus they do not depend each other for resources. Nor do they need to communicate with each other for coordination of work. However, they may use the resources provided by the collaboratory, such as knockout mice and databases whose raw data are provided by other collaboratory members.

Also funded by NIH, **Collaboratory E** aims to determine the 3-dimensional structures of proteins from M. tuberculosis. It consists of 134 labs from 79 institutions in 15 countries. Individuals in the collaboratory work on proteins that interest them and they inform the collaboratory and other members of the proteins they are targeting, as well as their progress and research methods, via the collaboratory website. The central cloning and protein production facilities of the collaboratory are cloning all of the *M. tuberculosis* genes targeted by any member of the collaboratory and testing the expression of these genes; the crystallization facility crystallizes proteins purified by individual members of the collaboratory and by the protein production facility; the X-ray data collection facility collects X-ray diffraction data on crystals from individual laboratories and from the crystallization facility. In addition to allowing the results of these tests to be made available to other collaboratory members, the collaboratory website makes this information available to the rest of the world. Similarly to Collaboratry D, participant scientists in Collaboratory E seek their own funding and conduct their own research. They do not depend on each other for resources or work. They are interested in identifying people who are performing similar research and knowing other people's work progress and research methodologies. The participants submitted their proposals first. After their proposals were accepted by the collaboratory, they became involved in the collaboratory.

Collaboratories F and G are collaborations of high energy physicists. These collaboratories are large, consisting of participants from almost 200 institutions in about 40 countries. Scientists need to obtain funding from funding agencies in their own countries to join in the collaboratories and aim to accomplish two major tasks—to build detectors and to perform physics analysis. The task of building detectors consists of many sub-projects; that is, participants from a few institutions collaborate to work on one or several components of the detector. For example, Chinese scientists in Collaboratory F contribute to the building of Muon chambers and are thus part of the Muon Project; Korean scientists are part of the team building Resistive Plate Chambers (RPC) and are independently on the component they are responsible for and communicate with other members of the sub-project when necessary for coordination. For example, the RPC group holds a project meeting every two or three weeks. Since this is the first time in which scientists from developing countries (China, Korea, Morocco and South Africa) build one component of the detector independently, scientists from developing countries learn technologies from scientists from the developed world. Scientists not only collaborate with those who work on the same component, but also need to contact those outside of this sub-group. For example, they sometimes need help from those who design and ship the parts of the component.

When performing physics analysis, scientists also form different research groups. For example, scientists who are interested in the particle Higgs tend to collaborate more closely with each other. They hold monthly workshops in which they report their own research progress, information about data acquisition, and updated software, etc. They also share email lists and wiki pages where they can exchange needed information.

However, because high energy physicists need to utilize various tools when conducting physics analysis they must also collaborate beyond their circle of scientists who share their interest in a particular particle. For example, since a collaboratory uses standardized software, to solve problems and obtain timely information about software updates, they need help from those who design and manage software. They also need to contact scientists who are familiar with the function of the detector to help them understand their data.

It is also notable that, unlike other collaboratories, Collaboratories F and G have a physical center, Institute X, which houses the detectors and concentrates high energy physicists from all over the world. Some institutions send their representatives to work in Institute X all year long so that they can inform people at the home institutions what occurs there. Some scientists try to visit Institute X as often as they can so that they can know the status of the detectors in a timely manner and gain more opportunities to meet with other specialists.

Building and maintaining a detector requires large amount of funding and much manpower. Thus, the collaboratories welcome forces from all over the world, whether they are from the developed or developing countries. When some institutions show their interests in joining in, the collaboratories assess the possibilities based on the funding situation and infrastructure of the institutions. After the collaboratories and the institutions reach agreements on the goals and ways of participation of the individual institutions, these institutions become involved.

PARTICIPANTS IN THE STUDY

Sampling of participants for interview within this study began with convenience sampling and was followed by snowball sampling methods. The purpose of the snowball strategy is to identify possible participants who are actively involved in collaboratories. A contact person, usually a Principle Investigator (PI) or a project manager was the source of initial recruitment. They pointed me to the scientists who were active participants of collaboratories, and these scientists in turn introduced me to those with whom they collaborate.

The interview participants from developing countries came mainly from China, Korea, Morocco, and South Africa. These countries were chosen for two reasons: first, in our database of collaboratories, these countries have the largest number of participants among the developing countries; second, the information technology infrastructure in the four countries represents different levels of development, with Korea being the most advanced and Morocco and South Africa the least advanced. In order to understand the perspectives of their collaborators from the developed world, I also interviewed scientists from the US and Europe.

Since that the designation of science originating in a developing country may not be equivalent to non-world class science (e.g., China does world-class seismology research)(Wagner, 2001), I examined the relative publication impacts of the developing countries in the past 10 years in the fields I studied, and found that the publications by the developing countries in these fields are all below the world average (www.in-cites.com).

Since the status of scientists also affects scientists' participation in collaboratories, I included both junior and senior scientists in my study. Junior scientists are doctoral students and postdoctoral fellows; senior scientists are experienced scientists who are capable to advise doctoral students.

DATA ANALYSIS

The data in my study consisted of transcripts from interviews; various types of documents pertaining to the scientists interviewed, including curriculum vitae, information about their labs posted on the website, and scientists' publications; various types of documents pertaining to the collaboratoreis studied, including scientific articles and news articles, the online documents posted on the website of different collaboratories (including introductions to collaboratories, annual reports, wiki pages, conversations in web forums); my own field notes; and pictures taken in various laboratories. Three transcriptionists transcribed my interview files, one for those in English, one for those in Chinese, and one for those in Korean. Since it was difficult for the transcriptionists to recognize the specialized language used by scientists, I provided a list of terms to the transcriptionists in order to improve transcription accuracy. After receiving the transcripts, I reviewed each transcript for accuracy and fidelity to audio recordings

Completed transcripts and field notes were imported into QSR International's NVIvo7 research software for qualitative analysis. Korean ones were excluded because the software cannot work on Korean documents. The interview and observation data were first analyzed separately, and then synthesized.

After carefully reading and rereading interview transcripts and field notes, I first coded the data for content. Then I analyzed them for emergent concepts and themes, which were organized into conceptual and thematic categories. The NVivo 7 research software enables me to visually sort conceptual themes within and across participant interviews, generate ' nodes' that allow me to aggregate conceptual themes across interviews, and produce 'trees' and 'memos' that enable me to construct interrelationships among these conceptual themes. Finally, I rechecked the data to verify that conceptualizations and emergent theoretical perspectives represented valid readings of the data (i.e. there were no counter examples).

METHODS OF VERIFICATIONS

Discussions of reliability and validity have been more adopted in quantitative research. Qualitative researchers hold different opinions regarding whether these concepts can be applied in qualitative research. At the extreme, some researchers (e.g., Roberts, 1998) contend that because the basic epistemological and ontological assumptions of qualitative research are incompatible to those of quantitative research, the concepts of reliability and validity should not be adopted in qualitative research. Most researchers, however, agree that like in quantitative research reliability and validity attend to issues regarding the quality of the data and the appropriateness of the methods employed in qualitative research. In this section, I will introduce strategies I adopted to pursue reliability and validity in this study.

Hammersley (1992) contends that reliability "refers to the degree of consistency with which instances are assigned to the same category by different observers or by the same observer on different occasions" (p67). In order to enhance reliability of their research, qualitative researchers should provide detailed procedures for data collection and data analysis, report researchers' biases, values and conceptual assumption, and record observations and interviews as concrete as possible (Creswell, 1994; Seale, 1999). Following these guidelines, in this chapter, I described details about subject selection, data collection and data analysis, and supplied my interview protocol and code books in the appendices. Earlier I reported that my pilot interviews helped me identify what theories and literature I should refer to in order to build the conceptual framework for the study.

Validity refers to the extent to which an account accurately represents the social phenomena that it intends to describe, explain or theorize. The most common methods to enhance validity include using many low inference descriptors, methods triangulation and data triangulation. (Johnson, 1997) suggests that verbatim, that is, the participants' exact words provided in direct quotations, is the lowest inference descriptor. Such verbatim enables readers of a report to experience the participants' perspectives by themselves. Thus, when reporting my findings, I included many direct quotations to illustrate the arguments I tried to make.

Triangulation is adopted because the more agreement of different data sources, the more valid is the study (Johnson, 1997). When employing method triangulation, researchers use various methods for data collection. In my study, I adopted semi-structured interviews, field observation and document analysis. As discussed earlier, a weakness of interviews is that what the participants say may be different from what they actually do. Through observations, I could see the participants' actual behavior, informing me whether what the participants said complied with what they did. Interviews helped me delve into the participants' reasoning, illuminating why the participants behaved in a certain way under certain situations.

Data triangulation, that is, using multiple data sources, was also adopted in this research. I conducted interviews with scientists from developing countries and their collaborators from developed countries. I interviewed both junior, senior scientists, as well as PIs. Understanding multiple perspectives of the same experience help enhance validity of my findings. For example, scientists from developed countries helped confirm what scientists from developing countries told me about their experiences.

SUMMARY

In this chapter, I reviewed the research methods used in my study. I first explained the rationale underlying research design, illustrating why qualitative approach is adopted, and why a more structured design was chosen. Then I introduced settings and research participants of the study and the coding process. I concluded this chapter with a discussion of reliability and validity of my study. The results of my study are reported in the chapter that follows.

CHAPTER 4

FINDINGS AND INTERPRETATIONS

In Chapter 2, I posed research questions regarding: (1) how collaboratories facilitate scientists to access resources, participate in communities of practice (CoPs) and networks of practice (NoPs), and learn knowledge and practices from scientists from developed countries; (2) What are the social, technical, cultural, and political obstacles that hinder scientists in developing countries from benefiting from collaboratories.

My results show that collaboratories enable scientists from developing countries to access resources and engage in both CoPs and NoPs with scientists from developed countries. However, the ways in which they achieve this are governed by many socio-technical and cultural factors. Because of distance, the size and dispersion of collaboratories, funding situations, and their local communication infrastructure, scientists from developing countries encounter more barriers than their collaborators in the developed world. In this chapter, I first report and discuss findings regarding how scientists from developing countries *benefit* from accessing remotely located *resources*, and the *barriers* to them accessing *resources*. Then there will follow a discussion of the *benefits* of and *barriers* to scientists from developing countries engaging in *CoPs* and *NoPs*.

ACCESSING RESOURCES

Some collaboratories, such as Collaboratories D and E, provide central resources and technologies that scientists cannot access in their individual institutions. As Dr. Seong [5]in Collaboratory E mentioned:

> I have almost all the technologies established in my lab except direct resolution, which was developed by the collaboratory. Because I'm working on one of the target proteins [of the collaboratory], I could apply the technology[6].
>
> Dr. Bennet from New Zealand also commented:
>
> One of the biggest benefits for us being part of Collaboratory E is the Synchrome facilities. So we can send samples to the person who runs the beamline in Berkeley, and she collects the data for us and sends it back. That's the biggest advantage for us.

Similarly in Collaboratory D, when Dr. Choi from Korea thought of looking for funding to establish centralized facilities to provide resources and perform data analysis in Korea, he found that Collaboratory B had already had the facilities and services that scientists in his field needed.

In other collaboratories, such as Collaboratories F and G in high energy physics, a detector, which is an essential instrument, is needed to perform experiments. Because of the cost of the instrument, thousands of scientists from all over the world need to work together to build the detector and share it after it is built. Only by participating in the collaboratories, can scientists access the detector itself and the data resulting from it. Thus, as Chinese, Korean and Morroccan, and South African scientists commented,

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[5] All the names appearing in this dissertation are pseudonyms.

[6] All translations are my own. I aimed to convey the meaning of the conversation, but not necessarily a word-by-word literal translation.

participating in Collaboratories F and G enabled them to “gain tickets” to the cutting-edge research in the field.

Scientists also reported barriers to accessing resources. All the participant scientists interviewed for Collaboratories D and E mentioned that because of the increasing number of participants, scientists have to wait longer and longer for the services provided by collaboratories, for example, the results of data analysis.

For scientists in Collaboratories F and G, where the data for research are contingent upon the measurement apparatus, gaining the ticket to access the detector does not guarantee actual access. In such collaboratories, it is important for scientists to obtain timely information about the changes in the detector. This information is frequently obtained through on-site informal communication. Scientists from developed countries travel to the site frequently and institutions from developed countries usually locate representatives on site in order to gain timely information. Dr. Thompson in Collaboratory F explained how an informal network at Institute X aided the spread of information:

> The information flows much better at Institute X. If there’s a problem, you’ll bounce it just over coffee. Everyone will tell everybody right quickly. There’s a fast human network of what’s happening. …There are many things like what’s happening today at the experiment. It’s not actually written anywhere because they are working like this. Now, I know because the person in my office was there this morning so I say to him “What’s new?” She tells me and someone else asks “What’s new?” and I tell them and this sort of information spreads. There’s no meeting about it.

However, scientists from developing countries cannot afford to visit the site as frequently or locate a person on site as easily. Thus, it is difficult for them to obtain timely information. As Dr. Thompson’s explanation continued:

> What happens to people who are not at Institute X is that they tend to know important things, but that was a few days late or even a week late or even a month, …after the information is posted or when they finally find there is a problem. Often a person has a problem, but he doesn’t know

> why. If he has a problem with the software, for example. It doesn't work. Why not? If he is here. He is like "the software doesn't work. Does anyone have any clue?" "Oh, you have changed something." But if you are outside, you would think, "Oh, maybe it's me. I'll try to fix it." You send an email to someone. They don't respond to your mail. Then you go to the meeting and you ask in the meeting, it's already two days later. [At Institute X], you already know the problem because somebody told you something else. They say "Oh,yeah, the server was down. The server crashed this morning because of the power cut." People off site don't know this. Here everyone is drinking coffee because there's no power where as this happens. It's an example.

What is described by Dr. Thompson indicate that scientists from developing countries cannot gain full access to the detector, unless they can access information about the changes of the detector in a timely manner.

Participation in collaboratories enables scientists to build research infrastructure in their local organizations. In Collaboratory A, all the important equipments required are purchased through NIH funds. In Collaboratories F and G, even though no common funds exist, because funding agencies in China, Korea, and Morocco considered that being part of these collaboratories indicates connection with the cutting-edge research in the world, they provide funding for scientists to build research infrastructure.

However, scientists are concerned about whether the infrastructure can be maintained after collaboratories conclude. Dr. Chen in Collaboratory A commented:

> We learned new technologies through participation [in the collaboratory]. It gave us a good infrastructure, and platform to do new research. And we now have some new thoughts on our research work and hope to conduct more independent research. However, I am worried whether we can gain funding from our national funding agencies to support our future research.

All the PIs in China and Korea in Collaboratoreis F and G express similar concerns. They state that the funding agencies do not have long-term plan, and they do not know whether they could still obtain funding after collaboratories conclude.

COMMUNITIES OF PRACTICE AND NETWORKS OF PRACTICE IN COLLABORATORIES

In collaboratories, scientists participate in both CoPs and NoPs. Table 2 summarizes CoPs and NoPs in the collaboratories studied. In CoPs, a newcomer-old timer relationship can be seen. For example, in Collaboratory A, Chinese scientists agree that they are less experienced in the research field such that research design is directed by US scientists, and Chinese scientists reported that they learn from US scientists. In Collaboratories F and G, when Chinese, Korean and Moroccan scientists work on a sub-project (e.g., building a specific part of the detector) with US and European scientists and need to communicate and coordinate work with each other, Chinese, Korean and Moroccan scientists agree that they are less experienced, and need to learn from US and European scientists. As discussed in the literature review, because it is difficult for scientists to have full knowledge of every component of the detector or every piece of software used for data analysis, physicists must seek each other's help for the knowledge of other part of the detector or software compiled by other scientists. In this sense, NoPs are also formed in Collaboratories F and G. In Collaboratories B, C, D, and E, scientists are not interdependent on each other for work, but they engage in similar research and share research methods and working progress, and thus they also form NoPs.

As discussed in the literature review, CoPs and NoPs mainly consist of two processes: to build fields of connection, and transfer knowledge and practices among the members. Thus, in this section, findings are grouped accordingly.

Table 2 CoPs and NoPs in the collaboratories studied

Collaboratories	CoPs or NoPs
A	**CoPs:** Chinese scientists are less experienced in the research area and learn from experienced US scientists.
B	**NoPs:** Participants collaborate to develop standard operating procedures (SOPs) for the collection, preparation, and distribution of liver samples.)
C	**NoPs:** The participant labs conduct experiments on the specimens independently and later collectively compare results and decide the standard for data collection to analyze plasma and serum protein constituents in humans
D	**NoPs:** Scientists share data, research methods in the research that aims to define the paradigms by which protein-carbohydrate interactions mediate cell communication.C
E	**NoPs:** Scientists share data, research methods and working progress to define 3-dimentional protein structure
F and G	**CoPs:** Participant labs are responsible for building different parts of the detector. While working on the sub-projects, scientists from developing countries learn from scientists from developed countries. **NoPs:** They seek each other's help to understand the functioning of different parts of the detector They seek specialists' help to understand the running of software.

Building Fields of Connection

Collaboratories concentrate scientists who share similar research interests or work on the same projects, and thus provide opportunities for mutual engagement. However, as discussed in the literature review, these opportunities cannot guarantee that collaboratory members pay attention to each other. Socio-technical and cultural factors including mutual dependency for work and for resources, the size and dispersion of collaboratories, funding situations, and communication infrastructure of participant institutions, all variously challenge scientists to establish fields of connection.

Importance of Building Fields of Connection

Research funding, the extent to which scientists depend on each other for work and for resources determines the ways in which scientists from developing countries access scientists from developed countries.

CoPs in the collaboratories are different from those described by Lave and Wenger (1991) in that old timers do not always feel an automatic need to assist newcomers' learning. In Collaboratory A, the US scientists who rely on Chinese scientists to access AIDS patients and conduct experiments to collect data, are motivated to maintain a close relationship with the Chinese counterparts. Because US scientists need Chinese scientists to collect data of high quality, they are also motivated to transfer technologies to Chinese scientists. In contrast, in Collaboratories F and G, scientists working on the same sub-projects have a vested interest in building relationships with each other, because they need to coordinate for the process of the project. However, the interdependency between participant labs is much weaker. Scientists from developed countries care less about the quality of work of scientists from developing countries. Thus, it is important for scientists from developing countries to seek to build relationships with scientists from developed countries in order to gain support from them.

In NoPs in collaboratories F and G, scientists also rely on other specialists to gain timely information or to acquire specialized knowledge. However, large collaboratories such as F and G, include about 2000 participants from all over the world, and thus many people are competing for the attention of specialists. Those who have personal relationships with the specialists will gain more attention. In contrast, in Collaboratories B, C, D and E, scientists are mainly interested in identifying those people who are conducting similar research, and learning their work progress and research methodology. Collaboratory members of this type are less motivated to build personal relationships.

How Do Collaboratory Members Build Fields of Connection?

Fields of connection enable scientists to create “collaboration readiness” (Olson and Hofer et al, 2008), whereby scientists share mutual trust, familiarity and are motivated to collaborate. Fields of connection also determine the way in which scientists access one another in CoPs and NoPs. Understanding its importance, collaboratory members deliberately seek to build fields of connection.

Some scientists select their collaborative members from those whom they know or trust from previous encounters. Before Collaboratory A started, the US scientists who initiated the application for funding from NIH, carefully chose their partners in China. They selected scientists with whom they had previously collaborated or whom they knew: one of the PIs in China, Dr. Liu, is located in a US institute, but also holds a part-time position in a Chinese university; Dr. Shang, got to know his US correspondent, Dr. Adams from various conferences and workshops, and thus became the PI for another site in China; Dr. Shen, who led the third site in China, had collaborated with Dr. Adams for about two years and worked at a US institute for about three to four months prior to the beginning of the collaboratory. Experiences of prior enable collaboratory members from different institutions build mutual trust, become acquainted, resulting in more efficient collaboration. As Dr. Thompson stated:

> [Video and teleconferences are] almost useless. I mean if you don’t know the people, you haven’t worked with them in person, my personal view is that it’s very difficult. I really think that. Typically it works well when you typically have been based at the lab so you spend maybe a year there. You get to know all the people, get to know what’s going on, you understand the environment. Then, if you go back to your home country, then you can follow by video, by telephone conferences and so on. Then, it’s effective because you know the participants. You know the contacts to work with.

What Thompson emphasizes is that experiences of working together enable the involved parties to know each other's expertise, work habit, etc., so that they can trust each other and better learn how to collaborate, such as knowing from whom to seek help. This is exemplified by the collaboration between the Morroccan team and a French Institute, Institute N. The leader of Morrocan team, Dr. Hanah, became involved in Collaboratory F because of his experiences of working with a French team in Institute N participating in the same collaboratory. He obtained his Ph.D. degree from Institute N, and continued his collaboration with scientists from that institute after he became a professor at a Morroccan University. He had worked with the team from Institute N participating in Collaboratory F for four years before Morroccan team formally joined Collaboratory F. After the Morroccan scientists joined Collaboratory F, they worked on the same sub-projects with scientists from Institute N. One of the French scientists collaborating with Dr. Hanah commented that the French scientists enjoyed working with Dr. Hanah and his team. Their previous experiences of working with Dr. Hanah secured their trust in his research ability. Their mutual understanding and good relationships also enabled the team members to align their goals. Thus, the collaboration was more efficient.

The way in which prior experiences of working together enable scientists to become mutually acquainted proves to be particularly important for scientists from developing countries, who need help from scientists from the developed world, but cannot afford to invite them to visit. Dr. Ching, a Chinese high energy physicist, responsible for a Chinese lab participating in Collaboratory F, worked for a year at a lab of University M in the US, which also participated in Collaboratory F. This experience enabled him not only to know the scientists, engineers and technicians of the lab at University M, but also those scientists and engineers from other US universities—for example, Dr. Milton from University B, who visited University M during his stay. Dr.

Ching commented that establishing a relationship with the US lab and US scientists were critical for him. Since it was his first time being responsible for such a project, he encountered many difficulties at the beginning. However, he never hesitated to seek help from those experts at University M, and they always assisted him patiently. They answered his questions regarding technical design, helped him order parts that he could not find in China, etc. Some scientists and engineers from University M subsequently traveled to China to solve problems that could not be solved through remote communication. Dr. Milton from University B visited the Chinese lab once to help solve some technical problems. Dr. Ching commented:

> When these US scientists came, they spent their own funding for the flight. I only took care of their expenses in Beijing. They don't even have any responsibility to help us. If we haven't worked together, it would have been impossible.

In Collaboratory F, no common funds exist to support collaboration between different participant institutions, nor do more experienced scientists from developed countries rely on scientists from developing countries for resources or work support. They do not feel an automatic need to help scientists from developing countries. In this case, building good personal relationships with scientists from the developed world assists scientists from developing countries in gaining help.

When collaboratory members do not know their collaborators before their collaboration begin, scientists seek to build fields of connection to ensure successful collaboration. In Collaboratories F and G, scientists from developing countries were able to join the collaboratory after they could secure funding from the agencies in their own countries. Then the executive board of the collaboratory, leaders of sub-projects, and participant labs in different countries discussed the possible sub-projects in which they could participate. Thus, while collaborators working on the same sub-projects did not necessarily knew each other at the beginning of the collaboration, they attempted to get familiar with each other before they began their collaboration. For example, when three Chinese institutions showed interest in collaborating with an Israeli team to work on one component of the detector, because Israeli team knew it needed more hands, they welcomed the Chinese teams. However, at the same time they were concerned about the capacity of the Chinese teams. As the sub-project leader, Dr. Grahm said, "we were very doubtful at the beginning because it was places with zero infrastructure and not a lot of knowledge on how to build the chambers."

A team of experienced scientists, led by the leader of the sub-project, visited China a few times. They were impressed by the Chinese scientists' strong will to become part of the collaboratory. Before the collaboration began, they also discussed with the Chinese scientists how the collaboratory as a whole as well as the experienced scientists on the subproject could aid Chinese science. Dr. Grahm described the process:

> … so we had quite a few visits one way and the other to build goodwill on both sides and then we had the visit of Professor Ha to our institute . We discussed how we go ahead on that. We agreed on starting the training in Israel and what kind of equipment do we send there. They made special lab that the was very much constructed along the lines of the lab that we had in Israel so people were familiar with those things and we send quite a bit of equipment there and we send technicians to help us start the work and following the work.

Thus, site visits before the beginning of the collaboration enabled the Israeli scientists to appreciate the strong will of Chinese scientists and understand what efforts they should make to help them. The Chinese scientists also became better informed about how they should plan for the participation in the collaboration.

Scientists get to know each other through conferences and workshops. There are several types of conferences in Collabroatory F and G: conferences for the whole collaboratory, at which scientists have the opportunities to meet representatives from all participant institutions, and conferences for various sub-projects, at which scientists meet those who work on the same sub-projects. For example, Muon conferences enable scientists working on Muon to meet each other; the collaboratory also organizes various training workshops on how to apply various statistics tools and software. Scientists reported that these conferences offer them opportunities for personal contacts with one another during coffee breaks, lunch and dinner time. These personal contacts facilitate their future collaboration. Mr. Huang, a Chinese doctoral student who was performing physics analysis described his experiences at conferences and workshops. He explained that in Collaboratory, all the data scientists use should be officially produced and recognized as correct, and thus he knew it would be helpful to know the person who was in charge of the work of producing the data. He got to know a person who produced the data he needed at a workshop. He recalled:

> I got to know a Japanese guy in a workshop, where he made a presentation. He introduced in the workshop what work he was responsible for. And I began to know what kind of problems he could help me to solve. [Later], he helped me in various ways. When I needed some simulation data for my physics analysis, I would tell him what kinds of data I need, and ask whether the data have been prepared, what kinds of data I want first. He would help us.

Mr. Huang further explained that in high energy physicists rely on other specialists (e.g. specialists in software tools, in data generation, etc.), and thus it is important for physicists to know others' expertise so that they can know from whom they can seek help. Informal communication at conferences or workshops provide opportunities for scientists to know each other better.

Mr. Huang emphasized the importance of this informal conversation and added that this type of communication cannot be replaced by email. He said:

> In email that person is only a name. But through interpersonal interaction, he is a human being. In email communication, when you ask a question, he would answer the specific question. But during informal face-to-face discussion, he would unintentionally talk about some of his thoughts and the problems he had experienced. That's a process of exchanging ideas. There is much more information in face-to-face communication. Through informal communication, I can know where his strengths lie and what his expertise is.

Thus, in contrast to communication through email, in which the conversation concentrates on a specific topic, face-to-face informal communication enables scientists to stimulate others' "unintentional" talk. This type of "unintentional talk" may provide useful background knowledge about what expertise he/she has. In other words, informal communication enables scientists to build common ground, which facilitates their future communication through information technology such as email.

Even in Collaboratories B, C, D, E, where scientists depend less on each other for work and resources, scientists benefit from informal communication at conferences and workshops. Collaboratories B, C, D and E hold annual conferences where collaboratory members meet and present their research. When asked how conferences help, Dr. Bennet, a New Zealand scientist in Collaboratory E commented,

> It's just the personal contact that is very valuable. Although I already knew some people before [the collaboratory] was formed, there were many more who became part of it since then. And I got to know them from a number of conferences.

Dr. Shin from Korea said,

> Only after you meet people, you can have a feeling about what kind of people they are. You can know whether you want to collaborate with them and how to collaborate with them. We meet people at conferences.

Some collaboratories have a physical center, which concentrates scientists from all over the world. In Collaboratories F and G, although scientists initially build components of the detector in their own institutions, the detector is finally assembled at Institute X in Europe, the center of the two collaboratories. As mentioned previously, many universities and institutions have their representatives stay at Institute X all year round. Senior scientists from US and Europe visit Institute X as frequently as they can. Many US universities support their postdoctoral fellows and doctoral students to stay at Institute X after they finish their coursework. Various workshops and meetings occur every day at Institute X, some of which are available through teleconferences and video conferences for those who are not physically at Institute X.

When at Institute X, scientists have more opportunities for personal contacts. They can have chance encounters with others during coffee breaks, lunch and dinner time. For example, in a building where most PIs of the collaboratory, PIs of many sub-projects and many visiting scholars stay, there is a coffee shop on the first floor. Around 10 to 11 o'clock in the morning, many scientists take coffee breaks and chat about research problems. For such a large institution, there are a few cafeterias, so most scientists congregate during lunchtime, chatting as they eat.

Scientists at Institute X can also go to find and talk to the specialists in their offices. A US postdoctoral fellow, Dr. Anderson, performing physics analysis, explained how he got to know people in charge of software. Once he encountered some problems when he analyzed data, he wondered that it might be because of the software. He looked up the documents and figured out who was the person in charge and he went to his office to ask for help. There he learned that the software had been updated, but he was still using a much older version of the software. After talking to him about this problem, Dr. Anderson got to know the person in charge of the software. He also met him occasionally at the coffee shop and cafeteria, and could chat with him during coffee breaks and lunch time. Dr. Anderson added:

> We are friends now. I can contact him (the person in charge of software) whenever I encounter some problems and he will help me.

Apparently, scientists who stay at or visit Institute X frequently have the advantage of being physically close to other scientists, and thus have easier access to specialists.

Figure 3 Scientist chatting during a coffee break in a building at Institute X

Figure 4 Scientists having lunch in a cafeteria at Institute X

Barriers to Building Fields of Connection for Scientists from Developing Countries

Scientists build relationships through prior encounters; previous experiences of working together; informal communication during coffee breaks, lunch or dinner time at conferences; and physical proximity to other scientists at the physical center of the collaboratories, if such a center exists. However, limited travel funding prohibits scientists from developing countries from going to conferences and workshops as frequently as their counterparts in the developed world. In Collaboratories F and G, characterized by many conferences for the whole collaboratory as well as for various sub-projects, scientists from China, Korea, South Africa, and Morocco all reported that they could only participate in two or three conferences a year, and for most of the time, only the project leaders even have these opportunities. Scientists from developed countries seldom mentioned these problems. When a physical center exists in a collaboratory, scientists who can stay at or visit the center frequently have more opportunities for personal contact. However, scientists from developing countries cannot stay or visit the center as frequently as their collaborators in the developed world. For example, the French scientists mentioned that a few scientists from their institutions stay at Institute X almost all year round, and their students stay at Institute X for one week every month. The US scientists interviewed also said that they had representatives from their institutions stay at Institute X all year round, and the senior scientists try to visit Institute X as frequently as they could. By contrast, due to limited funding, in Collaboratory F, only one person in one Chinese lab stayed in Institute X for several months in a year, and an exchange student could stay in the French institute with which Chinese scientists collaborate for half a year. Other scientists and technicians could go to Institute X when they are needed to help to install the detector. Korean scientists could only pay short visits to Institute X twice a year. Moroccan scientists mentioned that their heavy teaching loads made it impossible for them to stay at Institute X for a long time; they could only visit Institute X once or twice and stay at the most for one week during the semesters and for one month in the summer. Dr. Milton expressed his concern for Dr. Ching, his collaborator in China:

> Dr. Ching doesn't even know the people to talk to here. He knows me and some people from University M. But if he wants to get into data analysis or into any of those, he has to talk to the specialists here…
>
> It's easy to send email to me because he knows me. If he sends email to someone he never met, so that guy is like "what's the interest?" If he comes here and works here for half a year or one year, he knows the people and then he can go back and do the data analysis and come back every half a year and talk to the specialists. I think it's important for him to be here.

Dr. Stevenson from US in Collaboratory D further explained the importance of informal contacts and what scientists lose when they cannot access these contacts,

> The collaboratory is bigger on paper than it is in person. Some people are members, but they are too far away to come to the meetings. I guess [they are not] active members. …You get back what put in to a group like this. If you keep to yourself, you are not benefiting from this group.

In addition, fields of connection tend to degrade over time, and face-to-face interactions enable people to refresh them (Nardi and Whittaker, 2002; Nardi, 2005). Having fewer opportunities for personal contacts makes it more difficult for scientists from developing countries to refresh these fields of connection. Thus, the scientists become easier to neglect. For example, in Collaboratory F, scientists in one US lab complained that they could not know what occurred with their Chinese collaborators, because they could not see and communicate with them often enough.

One reason that scientists from the developed world collaborate with scientists from developing countries is to engage more manpower. Another reason that they choose to collaborate with scientists from developing countries is because they want to exercise more control over the direction of the project. For example, in Collaboratory F, a French institute closely collaborates with Chinese scientists to work on physics analysis of one particle, in which the French scientists are interested. When asked about why they collaborated with less experienced Chinese scientists instead of more experienced scientists from other countries, a French scientist answered that it was because it was easier to convince less experienced people to work on the subjects in which the French were interested. He also believed that because there was some time (about two years) before the experiment really started, there would be enough time to train Chinese scientists. This French institute could also obtain funding which supported their collaboration with scientists from developing countries, such as China and Morocco. The funding could support the expenses of visiting scholars and joint training of doctoral students from developing countries. French scientists believed that incorporating the manpower of Chinese and Moroccan scientists, they would form a stronger and more competitive team by the time the experiment starts. When working with scientists from developing countries, French scientists first invited Chinese scientists to work on some projects they initiated, and believed that in the process of working together, Chinese scientists would become more familiar with the tools required by the collaboratory and its associated conception of physics analysis.

It can be seen that in this type of collaboration, scientists from the developed world hold some expectations for scientists from developing countries. Their willingness to offer support results from these expectations. The relationship among scientists might be changed when the expectations cannot be met. Dr. Frank was interviewed twice. During the first interview, the Chinese scientist, who had worked with him at Institute X, had just been back to China. He talked about how the Chinese scientist learned from the experiences of working with French scientists. When Dr. Frank was interviewed for the second time about five months later, he began to express his concern with this collaboration:

> If it's really a collaboration, you should be independent. You're doing something we discussed. Maybe you can do this and this, and asked,

> "What do you think?" And you're part of the collaboration and say, "I want to do this." Ok, then do it. Then we can continue to discuss. If it's more like I said "do this,", and "when you finish this, I said again, "do this and this," it's not collaboration. It's "teaching." … It's not my job. I can do it when you start something, you need some teaching. Then you make your life. Collaboration means that it always comes from one side and the other side.

Obviously, Dr. Frank was expecting intellectual contributions from Chinese scientists after a certain period of training, and he was disappointed because he could see no evidence of what he had anticipated.

Dr. Frank also pointed out that distance exacerbated the problem. When the Chinese scientists worked at Institute X, they could come to speak with him face-to-face every week. He could see the results of their data analysis and receive timely feedback from the Chinese scientists. He explained that distance made it more costly to communicate with Chinese scientists. To understand the same problem, it took much longer than face-to-face communication. Sometimes it is difficult to identify whether the problems resulted from their local computing environment or from the updates of software of the collaboratory. He said:

> I don't want to spend hours each week just for doing this (meaning explaining things). It's not my job after all. I want to collaborate, which means I can spend hours, but the work should be progressing. It's not only, "doing this, this, and this …" There should be inputs from both sides. It should not be always one side leading.

The collaborative experiences between the French and Chinese institute suggest that after scientists build initial relationships, they need to maintain these relationships to ensure subsequent fruitful collaboration. Whether they can achieve this largely depends on whether the involved parties can meet their mutual expectation.

Transferring Knowledge and Practices in Collaboratories

Collaboratories enable scientists in developing countries to go beyond their local organizations and engage in and learn from communities of practice with scientists in developed countries.

Communities of practice benefit scientists in various ways:

On-site Participation and Observation

One complication with science is that much of its shared knowledge base is tacit, and learned only through participating in interacting communities of practice. Scientists from developing countries find that site visits, which enable them to work side by side with their counterparts in developed countries, are most helpful. They reported that through direct observation of their partners in the developed world, a different kind of learning takes place than what they can gain from books and conferences.

Working in their collaborators' labs in developed countries enables scientists from developing countries to learn the process of managing lab work. For example, in Collaboratory A of AIDS researchers, scientists need to conduct a clinic and laboratory series of procedures. They first collect blood samples in provincial clinics, arrange transportation of blood samples from clinics to the lab where experiments are conducted. Collaboratory A provides funding for selected Chinese scientists to work in their collaborative US labs for about three to six months. The specific scientists who visited the US lab reported that they could observe the whole working process, from collecting blood samples, and conducting experiments. When they returned to their own lab, they taught these procedures to other colleagues in their labs and began to implement these processes. Scientists from the US lab also visited the Chinese labs regularly to assist in the success of implementing these processes.

In a similar example, in Collaboratory F, when Dr. Lin and Mr. Song, who worked in their collaborators' labs in the US for three months and one year were asked about what they thought they would miss if they had not worked in the US lab, they both answered "lab management and quality control." As Dr. Lin, a Chinese high energy physicist described:

> We were very impressed by the way our American collaborators conduct their mass production quality control. For every chamber, they have a book [of guidelines for mass production quality control], which describes the detailed regulation for each process, from how to prepare the parts to testing and cleaning the parts. For each step, people who are in charge should sign the documents so that it will be easy to assign responsibility if problems occur…. I learned the management process and brought it back to our lab in China… Later, scientists and engineers from other labs in our institute visited our lab and borrowed our experiences.

The examples of how scientists in Collaboratory A and Collaboratory F learned management indicated that it is important for scientists from developing countries to be exposed to the whole procedures of management processes.

As discussed in the literature review, the quality of bench experiment is influenced by environmental and human factors. During site visits, scientists are also exposed to daily practices of their collaborators, and thus enable them notice some details important for the lab work they would otherwise never be aware of. Dr. Shen gave an example of what these details might be:

> Many factors affect the results of experiments. … It is difficult to reproduce an experiment in a different environment. [For example,] the quality of water is different. The water here might look exactly the same as that used in the US lab. But the water which has been boiled several times is different from that is boiled once. There are many other factors, too. For example, different technicians can also lead to different experimental results. When a technician does not clean the bottles carefully, the remaining chemicals there might be mixed with other chemicals, affecting the results of next experiment. Many bottles and tubes used in the US labs are disposable ones. But here the bottles are used again and again.

Working in the US labs enables Chinese scientists to notice these details. As Mr. Huang in Collaboratory A mentioned that when he visited the US lab, he noticed that they seldom put anything in the hood to avoid contamination of the experimental subjects.

In order to ensure the quality of experiment, US scientists in Collaboratory A also visited Chinese labs regularly. They can also moderate the details in which Chinese scientists and technicians conduct experiments. Mr. Wang, a doctoral student, explained:

> Each time they visited us, they paid more attention to the details that will affect the quality of data. For example, last time when they visited they suggested not put anything in the hood (?), because the virus or germs brought by the stuff might contaminate the blood samples.

Dr. Han gave another example of how site visits help Chinese scientists notice their errors in their experiments:

> We have a quality control process. Different labs [in the collaboratory] used the same samples or reagents sent by one core lab. Different labs then did experiments independently. If our results are not good, there might be many reasons. …It might be because of some errors our technicians made when performing experiments. If their technicians come to our labs and perform the experiments, they can see the problem results from the samples or the performance of our technicians.

Site visits are especially helpful for scientists in the transmission of tacit knowledge. For example, in AIDS research, when scientists use the Elispot method to evaluate vaccine-induced cellular immunogenicity, they use a machine called Elispot Reader. When Chinese scientists first learn to use the machine, the American scientists or technicians could instruct them on how to use the machine step by step through Webex. However, how to read test results cannot be learned at distance, because it is tacit knowledge. The test results appear as spots of variant sizes as shown in Figure 5. To read these results, scientists judge which spot may denote a positive reaction according to size. Based on this judgment, they set a standard, beyond which a spot is considered a positive reaction. Different scientists tend to have different judgments. They learn how to make correct judgments from more experienced researchers. As a Chinese doctoral student, Mr. Wang explained:

> When we first used this Elispot reader, we were not sure whether we were making the right judgments. Then I was sent to the lab in the US where the scientists are more experienced in this technology and worked with them for about one month. I conducted experiments there and I observed how they made judgments for the test results. Then I became more confident.

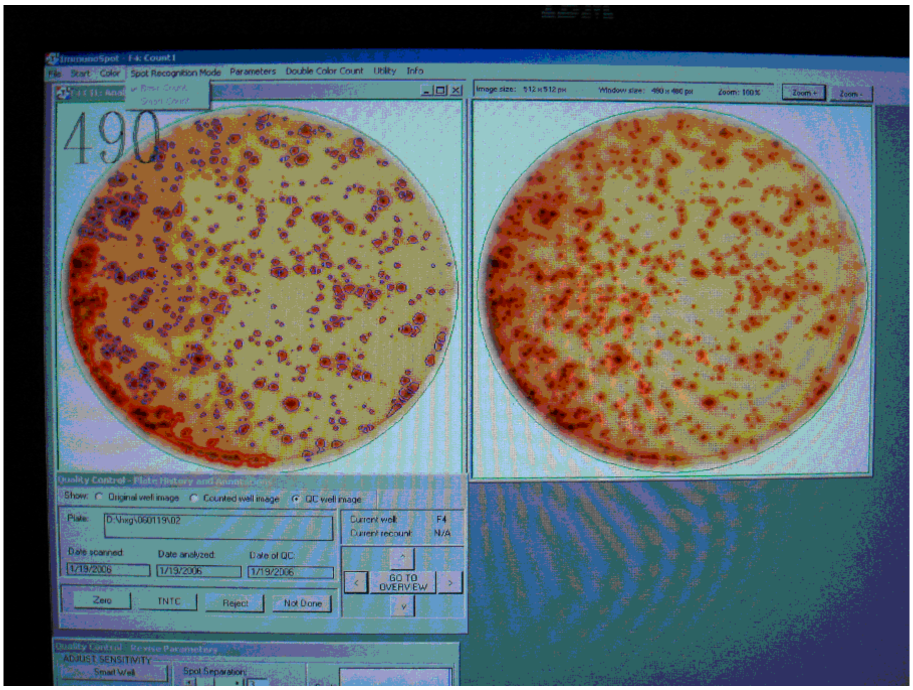

Figure 5 Results from an Elispot test

In Collaboratories F and G, building detectors involves many technologies, which can be acquired only through observation and participation. In Collaboratory F, a Chinese technician, Mr. Liang, offered an example. He described how he learned the technology of gluing tubes. When building chambers, tubes should be glued to the board. At first, Liang's understanding of chambers came exclusively from the drawings and pictures brought back by the scientists who visited other labs. Mr. Liang described it was a very difficult process, because it was difficult for him to "imagine" from the drawings and pictures how the tubes were glued on the chamber. Later, he was able to visit a Greek site and see the whole process of how the work was done. He said:

> The visit made a big difference. I noticed that when they applied the glue to the tubes, they first put a thinner tube between two tubes, which functioned as a "trail." The "gluing gun" (which is used to apply the glue) then followed the "trail." The width of the diameter and of the "trail" tube is related to the angle between the "gluing gun" and the tube when the glue was applied.

Mr. Liang added that the technology he described was not a complicated one. However, he would have never learned it if he had not seen how the Greek scientists and technicians performed the task.

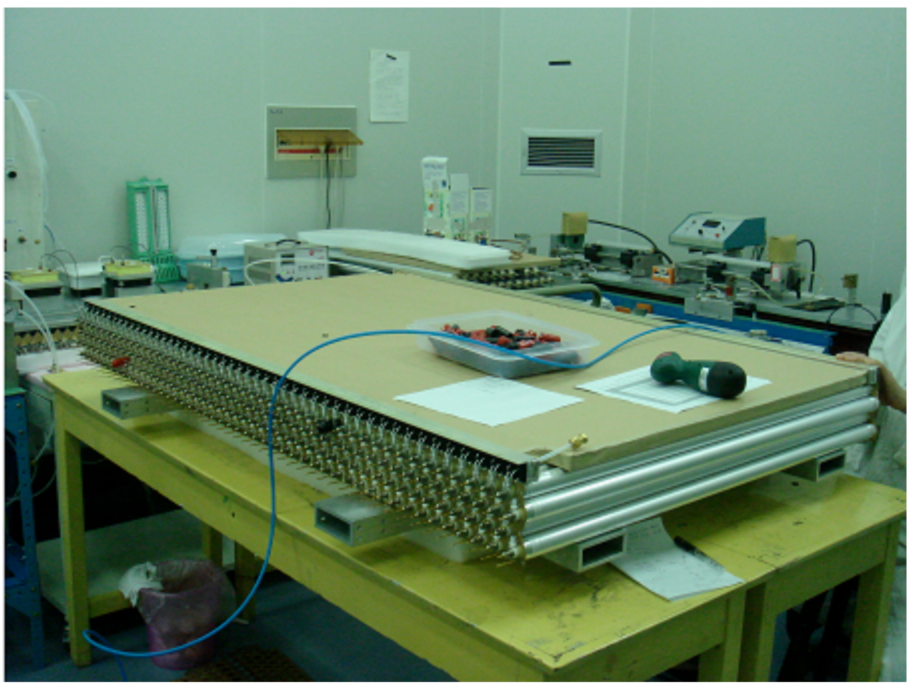

Figure 6 Picture of a chamber

Acquiring the technology itself is important. Learning the process of how the technology is designed can also be helpful. When asked about the benefits of working with scientists from developed countries, Mr. Song, a Chinese engineer working for Collaboratory G, cited exposure to cutting-edge technologies. He said he had the opportunity to work in their collaborators' lab in the US, where he was very impressed by a technology called the wending machine. The wending machine spread all the metal wires in the tube. This work had been done manually before the invention of the wending machine. When I asked him why they did not just purchase the machine and use it in his own lab, but needed to watch the process of how it was designed, he explained:

> In fact, the wending machine went through several versions. There have been many changes since the first version. In this process, many problems have been encountered. The final version is only the essence. But for me, the process is more important. Why? When I think about how to design such a machine, I need to think about how to [use it to] solve various problems. When the final product is presented to you, many problems have been solved. The information about [how to use it to solve various problems] is not described or told. It is different from when you participated in the whole process. You have used your mind, your brain to think about [the design and how to solve problems with your design]. It is different from when you only see the final product.
>
> For another example, this product is now delicate and of high precision. But how about when you don't need it to be so delicate, and of such high precision, because of your funding limit and because of different requirements? How about you need a more premature version? If you haven't participated in the whole process, you would never be able to do that.

What Mr. Song emphasized is that technology transfer should not only involve the technology itself. It is important to know the context of technology design; that is, what types of problems the technology is designed to solve. Only after understanding this context, can those who seek to learn it apply the technology in different contexts. To do this, the learner needs to participate and observe in the whole process of technology design.

Working side by side also affects scientists' attitudes toward work. Dr. Shen, an AIDS researcher in China, and his colleagues mentioned that they were influenced by their US partners' working attitudes. He commented that sometimes Chinese scientists tend to be more motivated by institutional reward, that is, by gaining promotion in their own organizations than obtaining recognition by the scientific community. They noticed that their US colleagues do not aim for “good work”, but “the best work.” Dr. Shen’s colleague, Dr. Chen told a story of one of his American colleagues:

> Once one of our American colleagues came to our lab to help us with an experiment. We arranged site seeing for her during the last day of her stay here. Two days before she went back, the experiment was finished. The result was satisfying, but she wanted it to be better. So she gave up the site seeing opportunity and continued with experiment until we got better results.

Informal Communication

Both informal and formal forms of communication serve communities of practice. Since scientists need to build upon and extend the work of others, and the validity of scientific work needs to be evaluated by other scientists, informal collegial communication plays an especially important role in scientists’ lives. In their study of scientists in academic as well as nonacademic settings, Pelz and Andrews (1976) find that productivity is associated with scientists’ communication among colleagues. Scientists in Collaboratories F and G also talked about how informal communication contributes to exchange of information and experiences among scientists.

A Chinese high energy physicist, Dr. Ching, explained that when they built detectors, much knowledge came from experienced people. It was significant for newcomers to access the experiences of oldtimers. Dr. Ching commented that informal discussion at regular project meetings, workshops, and conferences included many details that were helpful for participants to learn knowledge and information:

> When people make presentations, they can’t include many details. Then participants at the meeting would ask questions like, “How did it happen? What was the reason? What was the solution? Was it a good solution?” Then people would start discussion. Then the presenter would talk about more details, such as, “It is for this reason, the result looks like this.” He/she would also point out where they failed, and their experiences of solving the problems …Then other participants might question the presenter. They would say, “This problem does not result from this, but from …”

Dr. Ching is suggesting that formal presentation at meetings, workshops and conferences often play the role of a trigger, which arouse more informal conversations among participants. Scientists learn from each other from the details included in informal conversations.

Informal communication also enables scientists to obtain information in a timely manner. When asked about why information about updates of software was often obtained through informal conversation instead of official online publication, Dr. Yang in Collaboratory G commented:

> Generally speaking, a person like a librarian is in charge of updating software. The updated software is officially accepted, that is, software is officially updated after everybody agrees. But it is common that every software package has various errors. This is unavoidable. When many people [use the package] to perform data analysis, people find various bugs. They will report them in project meetings and remind other people. But these types of problems can't be reported online immediately.

In addition to aiding scientists in receiving information in a timely manner, informal discussions also allow them to receive stimulation from others. As Dr. Yang stated:

> At project meetings, some scientists might report a method, which they find effective in identifying a particular particle. This information can't be reflected by the officially published software in a timely manner. But if you know this information sooner, you can try other people's ideas sooner. Everybody has his own ideas. If you can know other people's ideas right away, you can always make progress. If you don't have this kind of information exchange, but only rely on officially published software information, you can't catch up.

Thus, informal discussion enables scientists to be more competitive by helping them receive information in a timely fashion and stimulation from others.

Informal discussion not only occurs at meetings, but also continues after the meetings finish. It goes on at coffee breaks, lunch and dinner time. As Mr. Huang commented,

> I discussed with them [those he thought he should talk to] both at the meeting and during coffee breaks. The time for the meeting is limited. Maybe during the meeting, they didn't think of the question thoroughly or because of time limit, it is sometimes better to discuss during coffee break.

Dr. Gang, a Chinese physicist, also commented,

> When I attended meetings at Institute X, it so often occurred that we couldn't agree with each other during the meeting time. Then our argument would continue to our lunch or dinner table.

The importance of informal discussion is confirmed by what I observed during a conference for a sub-project at Institute X. Dr. Lee, who is a leader of a Korean lab, has led his lab to finish building an inner part of a chamber. They planned to join in the building of the outside of the chamber. Dr. Lee came to the sub-project conference to find out the progress of the whole project, and to talk to people who could help them on their design of the chambers. After a session of the conference, Dr. Lee, as most of the participants did, came to the coffee shop on the first floor of the building. There he found Dr. Van who was the leader of the sub-project. He reported to Dr. Van briefly the design progress in the Korean lab, and what further materials they might need. Dr. Van suggested Dr Lee talk to Mr. Kline, a senior engineer, who was in charge of quality control of the sub-project. While they were talking, they saw Mr. Kline come to the coffee shop. They said "hello" and Mr. Kline also joined the conversation. Dr. Lee talked briefly about their design progress again. Mr. Kline said that most of the chambers made by other countries had been installed on the detector, and before the Korean side began to produce chambers, it would be important for them to know how much space was left and to design the chambers accordingly. Mr. Kline also suggested that it would be helpful for Dr. Lee to go to see the detector by himself so that he could measure the space left with him and could have a sense of where the chambers they built would be installed. He also kindly offered to drive Dr. Lee to the site where the detector was later in the afternoon.

Thus within 30 minutes, Dr. Lee met two experts, informed them of the problems from the Korean side, and made plans for the next step.

Another opportunity for informal communication in Collaboratories F and G is web forums, where scientists post their questions and wait for answers. Scientists can register for any web forums in which they are interested and can also choose to have the contents emailed to them. The following is an example of a conversation thread, where scientists discussed the updates for a piece of software:

Discussion title: Offline Software Help Requests

Hi Dave, I have not been able to run anything today. To whom should we complain or ask for fixing? Thanks, Edison

Discussion title: Offline Software Help Requests

I'm trying to get feedback from the local Linux support people. It looks like a new and incompatible version of libshift has been installed on at least some machines at Institute X. As far as I know there was no forewarning, and I don't know how extensive this new installation is, and what is planned. The new version breaks all ATT offline releases. Cheers, Dave

Discussion title: Offline Software Help Requests

Hi Jiri, I know how to correct that for my local machine but I would like to see a "global" solution for all users (and afs machines). Cheers, Ann

Discussion title: Offline Software Help Requests

"Hi EQ, my machine runs fine with athena since years (including the libshift part) and it ran fine 3 hours ago. I did not reboot (so no strange update could have been applied) so it would be interesting to know what has changed (lxplus machines are also affected). Cheers, Ann

Discussion title: Offline Software Help Requests

What happened is that a new incompatible version of libshift has been installed on some systems during the night - some have libshift.so. 2.0 while others /usr/lib/libshift.so.2.1. The old library has been removed. Because our software links to .so.2.0 it cannot find the library anymore. Cheers, Jiri

When one scientist posted questions, in this case why the machine could not be run, he could obtain various responses from different people. I interviewed Dr. Edison, who initiated this conversation. He commented that this type of web forum enabled him to gain help from many scientists within a short time.

In addition to offering answers to questions raised by scientists, questions and answers in web forums can trigger new topics for discussion.

> *Discussion title: Light quark*
>
> When I look into "Truth0" tree in TopView1213 and 1214, no light quark can be found and only 0ne b quark in each event. How to explain it? Thanks, Fang
>
> *Discussion title: Light quark*
>
> …t and s channel single top samples have leptonic decay modes only. Topview only keep the light quarks from W decay. If you need other particular objects (say spectator light quark in **t-channel**) then you will need to write your own tool…Anna
>
> *Discussion title: Light quark*
>
> I think including the spectator light quark in **t-channel** is quite important, as its direction is used as a basis for top spin analyses. I would like to include it by default in TopView v13   Marcus
>
> *Discussion title: Light quark*
>
> ….

In this example, the initial inquirer, Fang, asked why he could not find a light quark when he looked into "Truth0" tree in TopView1213 and 1214. In her response to the question, Anna mentioned t-channel. Then the discussion focus shifed to whether to include the spectator light quark in t-channel. Consequently, more scientists joined in and started discussions on a new topic.

The above two examples illustrate that scientists stimulate each other through online discussions, resulting in the discussions growing “up” and “out”. That is, in their responses to a question, scientists not only offer specific answers to the question, but also include subjects that the questions prompt. For instance, in the first example, when Dave first answered Edison's question, he did not simply say that a piece of incompatible software was installed. Instead he included contextual information, such as whom he had contacted, and there had been no forewarning message. Ann later joined in the conversation, and added historical context that her machine had run fine for years, indicating that this kind of problem had not often occurred. In the second example, scientists stimulated each other and realized that they should attend to a problem that they had not noticed before. Thus, online discussions in collaboratories provide arenas for improvised networks of practice. What distinguishes these networks of practices from those of Xerox repairmen discussed by Brown and Duguid (1991; 2001) is that networks of practice through online discussions allow a larger number of people from geographically distributed institutions to interact with one another both synchronously and asynchronously. Because all the conversations are archived, knowledge produced through the improvised practices in online discussions is recorded, enabling scientists to search for solutions to the problems they encounter later. In addition, online discussions can benefit those inexperienced participants, who sometimes hesitate to ask questions, because they were afraid that they would ask inappropriate questions. These inexperienced participants can be "lurkers" of online discussion. They "watch" other people's questions and answers and learn from them. As Mr. Huang, a Chinese doctoral student in Collaboratory F, described his experiences:

> Once I had a question about a piece of software. But I was not sure I could ask that. I was worried that I might look stupid if I ask this question. But the next day, somebody else asked the same question. So I got the answer without asking the question myself.

It is notable, however, that online discussions are more suitable for sharing explicit and factual knowledge such as in the first example, what has changed to a piece of software. I interviewed the initial inquirer in the second discussion, Dr. Fang. He commented that when the problems were more ambiguous and when he wanted to know more details, a face-to-face [*sic*] discussion would be much more efficient. He offered some examples of ambiguous problems:

> When I read the software code, if they can tell me how the code works, I will understand it well. Normally it is difficult to explain details [of how code works] in document, because each word might have different meanings. And it is difficult to read the code, which is not written by yourself. Sometimes you need more time to understand one line of code. But face to face (sic) will be easier. If I want to know what one variable exactly means, if we are face-to-face, He can tell me where this variable is defined and which value is used, and its exact physical meaning.

Here Dr. Fang indicates that when scientists help each other to solve ambiguous problems, they need to share objects, gain each other's feedback soon and respond accordingly. Online discussion cannot fulfill this need.

Online Document

Many labs document and post their work online. Scientists from developing countries reported that these online documents help connect them with scientists from developed countries, thereby informing them of the latest development in the field and enabling them to learn from scientists from developed countries.

Ms. Qian, a technician in a Chinese lab participating in Collaboratory F, mentioned that she could not contact her collaborators in foreign countries because of both a language barrier and the organizational protocol; she could, however, learn from the website of their collaborators:

> We are testing leakage of the tubes now. What we are doing in 2006 was done already by University M in 2004. They had a web site for the project. They documented the problems that should be paid attention to, and the phenomena you might see. For example, they said in the documents that lighting is very important. Then we tried to find the appropriate lights as described by them. After we started testing, we found that many tubes were leaking. I read the documents, and found that their examination had

been done more carefully. The O circles were examined under the amplifier in the lights. Then we did the same thing.

Ms. Qian emphasized that she could benefit from University M's website, because their documents were detailed and well-organized. These features made it easier for her to identify the information she needed.

Table 3 A section of micro array data (adapted from Collaboratory D)

Investi-gator	MicroArray Experiment	Samples Analyzed	Data Files	Gene-chip version	Data Analysis		Reqt(s)
filter	filter				Low Level	High Level (if performed by Core E)	
Frank Randal	Frank Randal 2: Glyco gene profiling of two Hela cell linesto help identify NKp30L expressed on tumoral cells	MicroArray Samples	Aug 20, 07 Public	GLYCO_v3_H			984
Yale Cook	Yale Cook 4: Changes in glycogene expression during maturation of dendritic cells	MicroArray Samples	Sep 01, 07 Public	GLYCO_v3_H			626
Paul Adams	Paul Adams 2: To analyze expression in the conjunctival epithelium of patients with severe dry eye disease	MicroArray Samples	Sep 01, 07 Public	GLYCO_v3_H			951
Smith Ryne	Smith Ryne 4: Examine differential expression of sulf-1 and sulf-2, enzymes involved in heparan sulfate biosynthesis	MicroArray Samples	Jul 20, 07 Public	GLYCO_v3_M			807

In collaboratories D and E, participants are required to post their working progress and their research methods in the databases of the collaboratories. Table 3 and Table 4 demonstrate a section of such a database in a molecular biology collaboratory. From Table 3, we can see that the database includes information about the investigator, what the experiment concerns and the results of data analyses. Table 4 contains more detailed information about a particular investigator's experiment. It explains when and how the experiment is conducted, what kinds of materials are used, etc.

Table 4 Explanation of an experiment listed in Table 3—MAEXP_XXX_XXX

General Information	
Experiment ID:	MAEXP_XXX_XXX
Experiment Title:	Frank Randal 2: Glyco gene profiling of two Hela cell linesto help identify NKp30L expressed on tumoral cells
Experiment Date:	07/11/2007
Status:	Public
Protocol ID:	
Experiment Description	
Dr. Randal lab's aim is to identify NKp30L expressed on tumoral cells. Preliminary Results: Two in vitro systems allow us to detect the NKp30L on the surface of target cells. The first reporter system is a reporter cell line expressing a NKp30 chimeric protein. Upon engagement of this chimeric protein with the NKp30L, cell activation specific for this interaction is measured. The second reporter systems uses the NKp30Fc recombinant protein as a detection tool or eventually as a blocking reagent. It is made with the sequence encoding the V-type Ig-like domain of NKp30. Work to qualify and define cell lines for the expression of NKp30L was carried out in order to identify in our two reporter systems the best cells lines to use. We finally identified the Hela EV2 and Hela PF cell lines as a positive and negative for NKp30L respectively whereas other NK receptor ligands expression is identical in these two cells lines. The NKp30L is sensitive to trypsin digestion and to PNGase F digestion in the NKp30Fc FACS staining assay. These results indicate that at least one NKp30L is probably a N-Glycan carried by a trypsin-sensitive protein at the cell surface. Requests: We would like to request a glycan profiling of these two Hela cell lines as this will be of major importance to help characterizing the differences in glycans between these two variants of Hela cells and the nature of the NKp30L. RNA preparations of Hela EV2 and Hela cells from EV23, EV2B, EV2III(positive) and PF4, PFB, PFIII (negative) cells were sent to the Microarray Core (E). The RNA was amplified, labeled, and hybridized to the GLYCOv3 microarrays.	
Associated Samples	
List of associated Collaboratory D MicroArray Samples	
Associated Resource Requests	
Collaboratory_rRequest_984	

These databases become the main forums by which scientists communicate. They help participants to avoid repetitive work and learn from each other. When asked about what he expected to gain from other members of the collaboratory, Dr. Song from Korea in Collaboratory E answered,

> [When conducting experiments], you have to try a lot of different procedures. Someone finds out that some procedures were better than other procedures. …If you have some information from other people about what is the shortest way and which can take the least time, that is very useful information. So we can share experiences.

He also emphasized that informal aspect of communication through these databases are particularly helpful:

> I like this database. From the publications, you can only get the success stories. But in this database, people also reported their failure experiences,

and I learned a lot from people's failure. If I know that method did not work, I will not use that method in my research.

Other online documentation that scientists find helpful includes minutes and presentation slides. For example, in Collaboratories F and G, various meetings and workshops occur almost every day. It is impossible for participants to attend each. Thus, the meeting minutes and presentation slides posted online inform scientists about what was presented at the meetings and workshops. Dr. Ching from China mentioned that because of the communication infrastructure and time difference, he could hardly attend any meetings, but he could "read" the meeting minutes and slides and learn about what others were doing.

Scientists in Collaboratories F and G also benefit from wiki pages, which include information ranging from the news of the collaboratories, the division of research groups, archives of reports of technical design, tutorials of various tools that scientists might use in their physics analysis, such as "Collaboratory F computing workbook," and "Collaboratory F statistics workbook." Wiki pages allow the beginners to learn about the project, and the experienced researchers to find information about its development.

Standardization of Working Processes

Some collaboratories require standardized work habits and work quality, in the administration of which inexperienced scientists learn from the experienced. Dr. Lu, a Chinese AIDS researcher in Collaboratory A, mentioned that he did not realize that the data produced in his lab was not of high quality until he collaborated with his partners in the US. Collaboratory A adopted quality control mechanisms. The same experiments were conducted in different labs in the US and China and the results were compared later. Chinese scientists feel that this kind of quality control helps to improve the validity of their work. Collaboratory A also has an advising committee that evaluates individual labs' progress at regular intervals. The committee consists of world-renowned scientists who assess what has been done well and what needs to be improved, and suggest future plans.

The collaboratory also has a database, into which participant labs regularly insert their data. Through the database, scientists can monitor others' working progress, and the reliability of the data each lab produces. By comparing their own data with the data produced by others, scientists can detect their own problems. Scientists can also find problems in other labs and identify them later through email or video or teleconference.

Translators and Knowledge Brokers

Translators and knowledge brokers also play an important role in promoting the spread of knowledge between communities. Brown and Duguid (1998) define translators as those who "frame the interests of one community in terms of another community's perspective." A good translator should have sufficient knowledge of both communities, be trusted by both communities, and be reliable to carry negotiations in both directions. In contrast to the role of translators, which mainly involves mediation, the role of knowledge brokers involves participation. A knowledge broker participates in the practices of several communities and broker knowledge between them.

In a virtual organization like a collaboratory, translators and knowledge brokers also play an important role, but in a different way than described by Brown and Duguid (1998). For Brown and Duguid, whose focus has been on management of corporations, translators aid the spread of knowledge between mutually exclusive communities, while knowledge brokers facilitate knowledge transfer among different communities within a corporation.

In collaboratories, however, translators not only participate in communities of practice in the institutions with which they are affiliated, but also engage in communities of practice or networks of practice with collaboratory members from other institutions.

Because collaboratory participants come from different organizations and countries, translators need to be familiar with the national and the organizational culture of involved parties in order to promote mutual understanding. For example, in Collaboratory A, where Chinese scientists collaborate with US scientists on AIDS research, scientists from both sides expected differences existed in policy and management styles, but did not anticipate the number and magnitude of differences. For example, in the US, PIs have more autonomy to use the project funds, but in China, use of funds should be reported to the institution, which delays the project progress. A Chinese scientist, Mr. Gao, mentioned that it was difficult to explain delays caused by such institutional protocols to their US collaborators. However, they could rely on a "translator" in this collaboratory, Dr. Xu. Dr. Xu was born and grew up in China, obtained her Ph.D degree in China, but received her postdoctoral training in the US lab participating in Collaboratory A. She served as the co-investigator on the US side of the project. Because she was familiar with both Chinese and US culture, she could explain the cultural differences to her US colleagues, enabling them to understand what they should expect from their collaboration. This is significantly different from the translators described by Brown and Duguid (1998), who are neutral third parties separate from the collaborating bodies. However, because the translators in the collaboratories exemplified by Dr. Xu are members of the collaboration, in addition to their familiarity with the organizational or national cultures of the involved parties, they have the advantage of understanding the collaborative project well.

Indeed, collaboratories seek such translators to minimize possibilities of problems caused by differences in institutional and organizational culture. In Collaboratory A, in addition to Dr. Xu, all the PIs of the participant Chinese labs played the role of translators. They all have the experiences of studying in the US, speak fluent English, and are familiar with the working environments of their US collaborators. As Dr. Adams, commented:

> I think, again, we have been quite privileged to work with three groups where their lead scientists have all trained for three or more years in the US. I think we are running this entire collaboration under kind of more or less I would call it international scientific guidelines. This works very well with all the collaborators there because they know the international system of research and communication. They have trained abroad. I can well imagine that if you would deal with or have to deal with Chinese scientists who didn't have the opportunity to leave China and have experience at the international conference, I think their cultural differences are more apparent.

Similarly, in Collaboraties F and G, the project leaders of participant labs, Dr. Ching, Dr. Liang, and Dr. Tang all have experiences of working in their US collaborators' labs for a few months or a year.

In the collaboratories studied, because scientists from developing countries are less experienced, knowledge flows mainly from scientists from developed countries to scientists from developing countries. Knowledge brokers are those who had been trained in the labs in developed countries. They brought back to their institutions what they had learned. For example, in Collaboratory A, selected scientists were sent to the US labs and received training on certain required technologies for about three months. After they came back to their own institutions, they trained other scientists or students. For example, when I did field observation in one of the participant labs in China, Mr. Gao, who was trained in the US lab, monitored three technicians performing the Elispot test to ensure uniformity with US lab protocols.

These knowledge brokers not only helped spread knowledge to those participating in the collaboratories but also to others who worked on different projects. When I visited a participant lab in Collaboratory A, a student working on a project unrelated to AIDS research came to visit the students trained for Collaboratory A. She showed them her data and asked students working for Collaboratory A to instruct her on how to read the data produced by the Elispot reader, a technique they learned as part of collaborative work.

Figure 7 Two students trained in Collaboratory A talking to a student working on another project on how to read the results from Elispot Reader

Similarly in Collaboratory G, Dr. Lin reported that after she adopted mass quality control that she learned from her US collaborators, scientists from other labs in her institution and even from our institutions came to visit her lab to learn from her experiences.

Scientists from developed countries can also be knowledge brokers. They introduced what they learned from their previous collaborations to their current collaborators in the collaboratories. For example, in Collaboratory A, the PI on the US side, Dr. Adams, had collaborated with African scientists on a similar project before Collaboratory A began. He learned from his collaboration with African scientists that transportation of blood samples could be a big problem in developing countries. He introduced to the Chinese scientists how the African scientists solved the problem.

Some scientists played the role of both translator and broker. In Collaboratory A, where scientists needed to collect blood samples from AIDS patients, scientists needed to obtain informed consent from the patients. However, when the collaboratory first started, no formal procedures existed to gain informed consent in China. The PIs on the Chinese side of Collaboratory A, who studied in the US, they were fully aware of the process in which US scientists obtained informed consent from the patients. However, they also realized that because Chinese culture is so different from US that they could not simply borrow the practices of their US colleagues. Thus, they endeavored to adapt what they learned from their US collaborators to Chinese culture. Dr. Shang in Collaboratory A proudly told me that the informed concent form they composed later became a national sample for scientists who conduct similar research.

Barriers to Transferring Knowledge and Practices in Collaboratories

Unable to Participate in On-site Learning

Although participants in collaboratories reported that they benefited from working side by side with scientists from developed countries, they could not visit their collaborators' labs as frequently as they desired due to limited travel funding. Collaboratory A provides travel funds to its members, and thus its scientists benefit from on-site training. However, in Collaboratories F and G, which lack common funds for travel, scientists could not access their experienced collaborators in the developed world as much. Difficulties in obtaining visas and heavy teaching loads also created barriers.

Unable to Participate in Informal Communication

Scientists in developing countries have fewer opportunities to participate in informal communication.

Table 5 A meeting schedule for Septemter 7, 2007 for Collaboratory (adapted from a meeting schedule at Insitute X)

09:00 - **Analysis Model Forum** (INSTITUTE X 40-S2-C01)
09:00 - **ALFA Electronics Technical Meeting** (Phone call 767 7000 ALFA Electronics; Anghin) (INSTITUTE X Room A)
09:00 – **M5 Pixel Commissioning** (INSTITUTE X 304-1-007)
09:00 - **CSC HG6 ttH/WH(H->WW) phone meeting** (INSTITUTE X)
09:30 - **TMB Thursday 13th September 2007** (M Nessi) (INSTITUTE X 40-4-C01)
10:00 - **DAQ/HLT commissioning** (Francis, David) (INSTITUTE X 40-R-D10)
13:00 – **Inner Detector Alignment Phone Meeting**
13:30 - **CTB analysis meeting** (INSTITUTE X 40-R-D10)
14:00 - **Atlas SM meeting** (INSTITUTE X 13-2-005)
15:00 – **ATLAS Muon Software** (INSTITUTE X 40-4-C01)
16:00 - **CSC Dilepton-Jets Meeting** (phone conference - dial +41 22 76 77000; Savinov, Vladimir; Stroehmer, Raimund) (INSTITUTE X 304-1-001)
16:00 - **LAr Detector + Cosmic Analysis Meeting** (INSTITUTE X 1-1-025)
16:00 – **SUSY CSC NOTE 8 (photonic, long lifetime)** (PHONE)
16:00 – **TileCal Commissioning** (INSTITUTE X 40-R-C10)
16:00 – **DDM Operations and SW integration weekly** (The meeting is dedicated to M4 data distribution) (INSTITUTE X 40-R-D10)
16:05 - **CSC Charged Higgs** (INSTITUTE X)
16:30 - **Combined Muon Reco and Common Tracking** (phone ONLY)
16:30 – **SUSY CSC 7 (gauginos)** (INSTITUTE X)
16:30 – **Z/W+Jets CSC note meeting** (INSTITUTE X 1-1-025)
17:00 – **A-Team Meeting** (INSTITUTE X Phone-only)
17:00 - **TRT SW** (INSTITUTE X 40-4-D08)

Scientists from developing countries participated in fewer video or teleconferences than their collaborators in developed countries because of poorer communication infrastructure. Moroccan and South African scientists in Collaboratory F reported that they could never participate in any video conference because of the low speed of their countries' telecommunications network. Neither could they attend any teleconference, because of their high costs. Chinese scientists also complained about the high costs of teleconference and low quality of video conferences. Dr. Lian from China mentioned that when he tried to make a presentation at a video conference, his presentation broke down so many times due to network problems that he had to stop his presentation in the middle.

Figure 8 Scientists in Collaboratory F having a video conference

Another barrier to scientists participating in meetings and workshops is the time difference. Many of the meetings and workshops in Collaboratories F and G are held from 9AM to 5PM, local time of Institute X, which was 3PM to 11PM in China and 4PM to 12PM in Korea. If Chinese and Korean scientists finish working at 5PM every day, there will be only two hours of overlap for the Chinese scientists and one hour for the Korean scientists. Thus, they would miss most of the meetings.

Some scientists tried to attend these meetings at home. However, they missed the opportunities to engage in informal discussion with colleagues in their own institutions. When I observed video conferences at University M and Institute X, I found that scientists often discussed with others present whatever they found interesting or problematic. If there were some interesting issues raised by the meeting, the scientists would continue their discussion even after the meeting ended. However, when a scientist can only attend meetings alone at home, he/she tends to miss stimulation from their colleagues who can be physically present at the same meeting.

As discussed in the previous section, when there is a physical center for the collaboratory, staying at the physical center, such as Institute X in Collaboratories F and G, where experts from all over the world concentrate, allows participants to get to know and engage in informal communication. They meet other scientists through chance encounters in the hallway, coffee shops, or at lunch or dinner. When they need help, they can go to talk to the experts face-to-face. Scientists from developing countries who cannot visit the physical center as frequently as their counterparts in the developed world have less access to informal communication occurring at the physical center.

Problems with Online Documents

Participants from developing countries learn much from online documents posted by institutions from developed countries. However, these online documents do not share the same quality across various institutions. Documents from some institutions include more details and are better organized. In addition, since participants in Collaboratories F and G are from all over the world, many detailed documents are not written in English. Most institutions do not have specialists in charge of the management of documents. For instance, Dr. Smith volunteered to manage web documents for University M. He tried to make sure the documents should be timely, detailed and well organized. However, he was concerned that he could not spend much time on these features in the future because of his other responsibilities.

In large collaboratories like F and G, many scientists contribute information, and thus there tends to be information overload. Scientists reported that they had difficulties locating useful information. For example, they obtain helpful information from wiki pages, but sometimes they could not locate the helpful page in need. They mentioned that informal communication with others is still one of the most efficient ways to help scientists locate information. When I observed project meetings, I often heard, “By the way, … do you know that Y used that software? You can find the information on their wiki pages."

Mr. Huang, a doctoral student who planned to obtain a joint degree from a French institute and Chinese institute, mentioned that when he stayed at the French institute, scientists there held weekly meeting with those staying at Institute X. Much information about software tools came from those colleagues who stayed at Institute X, because they had more chances to talk to the specialists. He did not believe that his advisers staying in the Chinese institute, who could not visit Institute X often, could be as well-informed as his advisers at the French institute. Thus, even though it is possible for scientists from developing countries to access information online, they cannot always know where the information was located or how to use it.

In addition, how much information a scientist can obtain from online documents mainly depends on how often scientists contribute to the documents introducing what they have done and how they have done it. Scientists in Collaboratories D and E stated that not every scientist reported their work as frequently and in as much detail as expected.

Cultural Differences

The hierarchical culture in Asian countries results in the leaders of the participant labs shouldering the tasks that they think important, such as video or teleconferencing with their remotely located collaborators, attending international conferences and visiting their collaborators' labs.

Scientists from the US and Europe considered the hierarchical culture an unnecessary barrier for the collaboration. When they hoped to talk to people who were directly in charge of the work, they had to communicate with the group leader first. For example, when a Korean lab decides to join the work of building the outside part of a chamber, Dr. Kim, a junior scientist, was responsible for technical design. However, it was Dr. Lee, the group leader, who went to visit Institute X to talk to the relevant specialists, and went to the detector to do measurement. When Mr. Kline, the senior engineer at Institute X, accompanied Dr. Lee to the site where the detector was and talked about technical design, he said several times to Dr. Lee, "Dr. Kim should be here."

Likewise, even though the leader of a Chinese group was not directly involved in the project, he was listed as the contact person for that Chinese participant institute, and represented that institute to participate in various conferences. Because he did not know the details of how the project was progressing, the collaborators from the US and Europe complained that they knew little about the Chinese site. The Chinese participants from that lab complained that the group leader went to most of the conferences, but could not supply them with useful information because he did not understand the project well.

As discussed in the previous section, scientists agree that participating in video or teleconferences and attending workshops and conferences provides them opportunities to learn from others through informal communication. However, when the group leaders think they must be the representatives to talk to outside collaborators, they tend to offer junior scientists, engineers and technicians fewer opportunities to participate in various meetings and conferences. When some doctoral students participating in Collaboraty G were asked whether they attended any video or teleconferences in their Chinese institute, they answered:

> You mean the video conference system upstairs? I have never been there. They are for our advisers to use.

The Chinese doctoral students had never thought that they could use that system to talk to others in the same collaboratory. By contrast, when I observed video conferences at University M in the US, the professors, engineers, and students who are involved in the project were all present and expressed their opinions.

Figure 9 Faculty and students of University M having a video conference

Korean students in Collaboratory G also said they did not participate in video and teleconferences often, because they thought their professors did not see the need for them to participate. In Collaboratory C, even though the PIs on Chinese side talked about the benefits of international collaboration, doctoral students working on the project even did not think it was an international collaboration, because they did not have chance to communicate with scientists from other countries.

Limited funding exacerbates the problems caused by hierarchical structure. In Collaboratories F and G, there are several types of meetings and conferences. In order to make full use of the funding, scientists from developing countries tend to combine a few trips into one. For example, when there was an important conference at Institute X, the group leaders from China and Korea went. The conferences that scientists from developing countries chose to attend usually require each participating site report management-related issues. Thus, the presence of group leaders was required. They usually arrived a few days before the conference started so that they could talk to some specialists at Institute X. Although the group leaders may not be the best people to talk to the specialists, they cannot afford to send other scientists to visit Institute X as frequently as needed.

Hierarchical structure did not only exist within China and Korea. Chinese scientists also brought this to their relationships with US collaborators. In Collaboratory A, acknowledging that they were less experienced, some Chinese participants accepted that they should be directed by US scientists, as the Chinese scientists were unwilling to voice their own opinions. Suggested by US scientists, Collaboratory A first adopted a low-bandwidth video conference system for their monthly research meeting, but later switched to teleconferencing. When interviewed, many Chinese scientists stated that they preferred the video conference system, because the system allowed sharing presentation slides and instant messaging to individuals. Those scientists who did not speak fluent English explained that it was difficult for them to understand US scientists by listening to them without the aid of presentation slides. However, when asked why they did not tell the US scientists their difficulties, they said they did not think they were in the position to give suggestions regarding what system to adopt.

Unfavorable National and Organizational Policies

Restrictions from national and organizational policies hinder scientists in developing countries from benefiting from collaboratory use.

Collaboratory A requires exchanges of blood samples. In the US, there is a sophisticated social system to support the transport and exportation of blood samples. In China the system is still inadequate. In AIDS research, it is important to transport the blood samples from the sites where they are collected to the labs where the experiments are done within a short time to ensure the quality of the blood samples. In the US labs, the sites where blood samples are collected are either close to the labs or the blood samples are transported through FedEx. In China, however, the blood samples were collected from several local provinces and the experiments were conducted in Beijing far away from those provinces. Scientists also need to obtain permission from both local and national governments to transport blood samples. The application processes often led to the delay in blood sample transportation.

The Chinese government also imposes strict restrictions on exporting materials related to biological research. The scientists need to apply to different levels of governmental offices to obtain permission for exporting blood samples. Dr. Lu., the AIDS researcher in Collaboratory A, reported that it took them seven months to export the blood samples their US partners needed. For US scientists, it took three days.

Beyond Transferring Knowledge and Practices

In the last section, I discussed how specific knowledge and practices are transferred from scientists from developed countries to scientists from developing countries. However, in addition to acquire specific knowledge and practice, scientists from developing countries also demonstrate and urgent need to build general competence for a variety of future research. In this section, I will discuss what competencies scientists from developing countries need to gain, and how collaboratories facilitate or hinder their acquisitition of these competencies.

Collaboratories help scientists build capacities by encouraging them to participate as representatives of countries, not as individuals. Dr. Grahm, experienced in working in Latin American countries and now a project manager in Collaboratory F, claimed that there were two models of participation in international collaboration for scientists from developing countries: individuals join in various projects in large labs in the US and Europe, usually because the large labs need manpower; or an individual country participates as a group, responsible for part of the collaborative project. For example, in

Collaboratories F and G, many participant countries independently shoulder the task of building part of the detector. According to Dr. Grahm, the latter model gives a country more opportunities to make impact. Dr. Grahm used Poland as an example to illustrate this point:

> If you take a country like Poland, traditionally people worked in every possible experiment in the world at the level of individuals and now for the country, they actually try to concentrate on a few experiments. That gives a country a much stronger base and much stronger influences. It is true that this is good for the local community. It is true that this is good for an experiment themselves since having one group making a major contribution.

In order to be able to make contributions, scientists need to have the necessary "know how" and infrastructure in their local research communities. Dr. Grahm further explained what "know how" and infrastructure are needed:

> Know how means from the capability to do a community project to the capability to perform analysis at the computer infrastructure and to have the right communication ways to be able to make the contribution. .

Leading scientists who understand how to build and lead research teams in general also constitute an important part of local research capabilities. These scientists should know how to assess needs of infrastructure and manpower, and understand how to communicate with collaborators from other organizations. Or, in Dr. Grahm's words, they have "a global view." However, when individual scientists participate in projects in large laboratories, they are frequently trained for one specific task and learn highly specialized skills and knowledge, and thus cannot have this "global view." Dr. Grahm criticized this model of participation for scientists from developing countries:

> In my opinion, [training scientists for one specific task] has been…big mistakes that were done in the US in the large labs. They try to attract people for high energy physics from the Latin American countries because when you bring somebody to a big lab and for project purposes …what you need are people that are highly specialized in one particular thing. Because everything is more distributed, you make a specialist in one particular point of the experiment and now you expect this guy to go back and be able to establish a group and he has no idea.

Dr. Grahm suggested that working in a small research group first offers the training such leaders need. His view is confirmed by the experiences of Dr. Ching in Collaboratory F, who worked at University M in the US for a year and later returned to China to build his own research team. He observed how the team was built, its composition and its collaboration methods. He also emphasized that observing the reviewing process was particularly helpful. Collaboratory F holds annual reviews for each participant site, examining the infrastructure, working progress, etc. Dr. Ching had the chance to participate in the reviewing process when he worked at University M. He stated that by observing the review process he could understand the expectations of the collaboratory and how a team should contribute.

Some scientists consider it crucial for scientists from developing countries to improve their capacities to perform research. Dr. Tan, a US scientist from Collaboratory A, suggested that compared with scientists in the developed world, what their Chinese collaborators need to improve includes to understand "what kinds of questions to ask," "how to do data analysis," "how to get the data out," and "how to write a paper to report their finings." Dr. Tan's concern was echoed by Chinese scientists Dr. Tao and Mr. Jiang in Collaboratory B, who stated that they needed to catch up with scientists from the developed world in terms data analysis. They observed that "from the same set of data, people find different things, and scientists from the advanced labs tend to find more interesting results."

Dr. Tan also suggested that the best way for scientists to acquire the ability to perform study design and data analysis is to immerse themselves in the practices of the advanced labs. When asked about what scientists can learn in an advanced lab, Dr. Tan did not emphasize learning from individual scientists, but rather the "group thing."

> I think it's the atmosphere, the research atmosphere. Here we have … broad topics. We have over 50 people in the lab including postdocs and PIs. Everybody was talking about so many things. So you absorb information every day. It might

> be something useful for you to analyze your data. It might give you a spark and you find that there is something … to think about to get something out of the data. … In China, they read a lot of scientific journals, [but] you may not really get the idea you get through discussion. Here everybody was talking about it all the time. Even when I am in the lab, somebody might mention, "I saw a paper that might be interesting for you…" It opens up to something there. So … it really depends on the group, the atmosphere.

Dr. Tan also emphasized that information technology enables scientists from developing countries to learn from scientists in the developed world. For example, she said in Collaboratory A, when Chinese scientists wrote papers, the US scientists would read their draft, make comments and suggest other relevant readings. However, this kind of learning cannot be compared to what scientists learn from lab practices directly and by themselves, as Dr. Tan commented:

> How much they can get when it is given by somebody else is different from what you can get yourself.

Dr. Tan's comments indicate that the advanced labs in the developed countries tend to concentrate more experts, and thus provide the scientists an environment where they can obtain greater stimulation and information from their colleagues.

Dr. Yan, a Chinese scientist in Collaboratory A echoed Dr. Tan's comments. When asked about what benefited her the most from her three-month stay in the US lab, she answered:

> Here in our lab, I only focused on how a technology or method could be applied to the research subject in which I'm involved. But in the US lab, there were many groups working on different projects. They might apply the same method, but in different research subjects. …and the study design varies. The single technology can become a platform, based on which many experiments can be conducted. This really broadened my view.

The "group thing" described by Dr. Tan and Dr. Yan is similar to Orlikowski's observation that the core competencies of a system emerge from its daily practices. The competence of the US lab in Collaboratory A is not attributable to say, a renowned scientist or an advanced instrument, but is "an ongoing accomplishment" of the lab's

CoP. It is not given or stable, and can thus only be achieved by participating in such communities of practice. However, when Chinese scientists were in China, even though they could communicate with US scientists regularly (once a month through video or teleconferences), they could only access a few scientists from the US lab, but not the practices of scientists in their daily routine.

Some scientists expressed their hope to work in advanced labs in developed countries, because they believed this is the way through which they can learn the local knowledge and experiences of the lab. Dr. Chang in Collaboratory B mentioned that among the participant labs in the collaboratory, the Chinese lab could earn the largest amount of funding from the Chinese government. Thus, the lab was equipped with the most advanced equipments in the world. However, he does not consider his lab world-class. He said that the lab has much to improve upon in terms of skills and techniques. He commented:

> Even when we use the same equipment and the same materials, the more advanced labs might get better results. The difference results from our lack of accumulation [of experience]. We need to improve our skills and techniques. Speaking of skills and techniques, it's not to say that individually they are better than we are, but they had a lot of accumulation—the accumulation of the experiences of the whole lab. To learn that, I need to be in the lab to experience the atmosphere myself.

Dr. Chang's comments confirmed the existence of local knowledge in individual labs and the difficulty of acquiring such knowledge. As revealed in the literature review, biological studies contain much local knowledge, which tends to be passed on to the next generation in the lab through informal communication and lab practices. In addition, performing experiments is artisanal. It is difficult to codify how the body of experienced scientists remembers and performs. Thus, the expert know-how of the experienced scientists can be learned from direct observation and the practices of labs persist through the narrative culture of the laboratory, its story telling. Laboratories which have long history and a solid foundation of performing basic research tend to accumulate more local knowledge. In order to acquire the local knowledge of individual labs, scientists must be exposed to the practices of those laboratories.

Even though it is important for scientists from developing countries to participate in CoPs in labs in developed countries to gain knowledge enacted by daily practices and embedded in the labs' narrative culture, the current collaboratories tend to focus on training scientists to learn only that knowledge and those practices needed for specific tasks, but do not pay any endeavor to increase scientists' capacity to perform research. Dr. Tan mentioned that Collaboratory A provides training funding for Chinese scientists to learn advanced technologies. However, the funding tends to focus on training scientists learning the technologies needed for data collection in China. As Dr. Tan commented:

> Usually the funding supports Chinese scientists to stay for about three months in our lab for training. From science perspective, if you want training on technique, that's ok, because you basically got the idea. But if you really want to take over the project or study to design the project, three months is definitely too short.

SUMMARY

In this chapter, I reported and discussed what I found through interviewing scientists and observing their work. Collaboratories enable scientists from developing countries to access resources they cannot obtain in their local organizations, and participate in communities of practice and networks of practice with scientists from developed countries. Scientists from developing countries build fields of connection with and learn from their counterparts in the developed world through site visits, informal communication, online documents, etc. However, barriers—including limited travel funding, cultural differences, poorer local communication infrastructure and unfavorable governmental policies--hinder scientists in developing countries from maximizing the benefits these collaboratories offer. In addition, scientists from developing countries demonstrate an urgent need to build general competence in performing research. This can only be achieved through long-term exposure to the practices of advanced laboratories in the developed world. However, the project-oriented nature of collaboratories and the funding mechanisms have failed to support the need.

CHAPTER 5

CONCLUSIONS

This chapter serves several purposes. I begin by reviewing the key findings from my study. Then, I discuss theoretical, policy and design implications of the study. Finally, I analyze several limitations of my study and suggest areas for future research.

OVERVIEW OF THE MAJOR FINDINGS

The study identified environmental factors leading to scientific productivity, such as resources, communities of practice (CoPs) and networks of practice (NoPs). The literature review also pointed out factors that affect participation in CoPs and NoPs. This study examined how these factors play out in collaboratories, which consist of geographically distributed institutions that display inequality in resources and research competence across institutions, and difference in national and organizational culture. My investigation highlighted how collaboratories benefit scientists from developing countries and revealed barriers that hinder collaboratories from maximizing their potential benefits.

My main research questions included: to the extent that inequality in resources and research competence across participant institutions, geographic dispersion, cultural difference, and use of information technologies affect scientists from developing countries to access resources needed for research and participate in CoPs and NoPs, what are the effects of collaboratories on scientists from developing countries? I defined the effects of collaboratories on scientists by the following sub-questions: How do collaboratories benefit scientists from developing countries regarding accessing resources, building fields of connection and accessing knowledge and practices of scientists from developed countries? What are the social, technical, cultural, and political obstacles that hinder scientists in developing countries from benefiting from collaboratories? My results showed that collaboratories enable scientists from developing countries to access resources that cannot be provided by their local institutions, and engage in the CoPs or NoPs with scientists from developed countries. However, dependency relationship between participants, geographical distribution and cultural difference affect whether collaboratories can reach their potential.

Effects of Dependency Relationship

In the collaboratories studied, collaboration between scientists from developing and developed countries has a significant component of learning. In general, compared to participants from developed countries, participants from developing countries are less experienced in the research area. Collaboratories offer scientists from developing countries opportunities to learn from scientists from developed countries through CoPs and NoPs.

However, different from the self-contained apprentice types of CoPs described by Lave and Wenger (1991), in collaboratories, the newcomer-old timer relationship is masked by the notion of collaboration. In the apprentice type of CoPs described by Lave and Wenger (1991), the master-apprenticeship relationship is agreed upon, and the roles of each community member are well defined. However, in a virtual organization like a collaboratory, where participants are expected to collaborate, scientists from developed countries do not feel an automatic responsibility for supporting the learning of scientists from developing countries. The dependency relationship between scientists from developing countries and developed countries determines how easy scientists from developing countries can access scientists from developed countries.

When scientists from developed countries consider that learning by scientists from developed countries have a significant impact on their collaborative work, or when scientists from developed countries depend on scientists from developing countries for resources and manpower, scientists from developed countries offer more support. For example, in Collaboratory A, where resources needed for research reside in China, and US scientists rely on Chinese scientists to collect data, the more experienced US scientists have vested interests in transferring knowledge and practices to the Chinese scientists. By contrast, in Collaboratories F and G, where scientists from developed countries do not feel the immediate impact on their work even when their collaborators from developing countries cannot perform high-quality work, they feel less need to aid their collaborators in developing countries.

My research results showed that building personal relationships can help scientists from developing countries overcome the restrictions of dependency relationship and gain more access to scientists from developed countries. Scientists build relationships through prior experiences of working together, site visits, side conversations at conferences and personal interactions at the physical center of a collaboratory (if there is one). However, because of limited travel funding, scientists from developing countries cannot have as many opportunities to build relationships as desired. Common funds of collaboratories can also motivate scientists from developed countries to visit the labs in developing countries and enable scientists from developing countries to go to conferences and visit the labs in developed countries more often. However, except Collaboratory A, the other collaboratories studied do not provide common funds.

Dependency relation in NoPs is different from that in CoPs. In NoPs, where the member relationships are more lateral, participants expect others to provide "social affordances" (Brown and Duguid, 1998). For example, scientists expect to gain stimulation from each other from discussions in research meetings or through online discussions. Thus, NoPs will fail when the mutual expectations cannot be met. In NoPs in collaboratories such as D and E, where scientists share raw data, research methods and working progress through databases, it is important for scientists to post their research frequently so that NoPs can be sustained.

The dependency relationship also changes over time, affecting sustainability of CoPs or NoPs. Sometimes scientists from developed countries agree to support the learning needs of scientists from developing countries because they hope to engage more manpower. They believe that after a certain period of training, they can gain intellectual contributions from scientists from developing countries. In other words, scientists from developed countries hope that their relationship with scientists from developing countries can change from old timer-newcomer relationship in CoPs to a more lateral relationship of collaboration in NoPs. In this case, when scientists from developing countries cannot meet the expectation from scientists from developed countries, it is difficult for collaboration to be sustained.

Effects of Geographical Dispersion

Time difference affects the ability of scientists from developing countries to access scientists from developed countries. Effects of time difference also interact with effects of peripherality. For example, in Collaboratories F and G, various research meetings are held every day. However, the meeting schedules tend to accommodate the needs of US and European scientists, because a larger number of participants are from these two areas. Times when both US and European scientists work are usually late night of local time in Korea and China, making it difficult for Chinese and Korean scientists to attend these meetings.

Effects of geographical distribution interact with effects of dependency relationship. Scientists reported that when communicating at distance, it takes a much longer time to understand the same problem than face-to-face communication. Scientists from developing countries will not make efforts to communicate with scientists from developing countries at distance unless they feel an urgent need to do so, even though this kind of communication will benefit scientists from developing countries. For example, as reported in Chapter Four, in the collaboration between French and Chinese scientists, when French scientists find that Chinese scientists cannot make intellectual contribution as expected, they do not show strong interests to install a video conference system as suggested by Chinese scientists.

Effects of geographical distribution interact with effects of inequality in resources across institutions. Poor communication infrastructure and limited funding result in fewer opportunities for scientists from developing countries to participate in CoPs or NoPs. When at distance, scientists employ information technology to communicate with their remotely located collaborators. However, because of poor communication infrastructure, scientists from developing countries cannot participate in video or teleconferences as frequently as their collaborators in the developed countries. Conferences and site visits offer scientists opportunities for face-to-face meetings, enabling them to gain better acquaintance and learn from each other. However, limited travel funding results in fewer opportunities for scientists from developing countries to attend conferences or visit their collaborators in other countries.

Effects of Cultural Difference

Because collaboratory members come from different institutions in different countries, cultural difference affects CoPs and NoPs in collaboratories. Culture difference may cause difficulties in coordination for collaborative work. For example, scientists from US and Europe in Collaboratories F and G complain that they cannot contact the Chinese and Korean junior scientists who do real work, but have to communicate with the senior scientists first. Because of hierarchical culture in China and Korea, junior scientists there have much fewer opportunities to access scientists from developed countries and their practices. Scientists also bring their national or organizational culture to the collaboratories. For example, in Collaboratory A, Chinese scientists think US scientists should play the role of collaboratory leader make decisions, and thus they do not voice their opinions regarding which video conference system to adopt.

The research results also showed that translators help to alleviate the negative impact of cultural differences. Different from the translators described by Brown and Duguid (2001) who need to be mutually exclusive from both communities involved, translators in collaboratories are those who are affiliated with one participant institutions, but have experiences of studying or working in the countries of their collaborators. Their familiarity with national and organizational culture of their collaborators enables them to explain to their colleagues in their local organizations and their remotely located collaborators what to expect when conflicts and misunderstandings are likely to occur.

The Role of Information Technology

As discussed in the introduction section, researchers hypothesize that collaboratiories will greatly benefit scientists from developing countries, because various information technologies adopted in collaboratories enable them to access remotely located instruments, databases and experts. As summarized in Table 6, my research results showed that information technologies enable scientists to overcome somewhat geographical barriers and engage in CoPs or NoPs with scientists from developed countries. Scientists from developing countries have opportunities to discuss research questions with scientists from developed countries through email, video or teleconferences. They also learn from the documents posted online by their collaborators in developed countries.

Table 6 Information technologies in collaboratories

CoPs and NoPs	Collocated, synchronous	Distant synchronous	Asynchronous
Building fields of Connection	Site visits; side conversations at conferences; informal interactions at the physical center (chance encounter, coffee break, lunch and dinner time)	Informal communication at video conference and teleconference	
Transferring knowledge and practice	Working side by side during site visits; informal communication at face-to-face meetings	Informal communication at video and teleconferences	Email lists, shared database; online forums; online documents

However, these information technologies are limited in different ways. Email and online discussions are only good at discussing questions that can be clearly described, but cannot be used for ambiguous ones. Due to the technology infrastructure and time difference, it is difficult for scientists from developing countries to participate in video or teleconferences. It is also difficult to follow up video or teleconferences with subsequent discussions. Online documents are helpful, but scientists do not always remember to document their research experiences, and not all the documents can be as well-organized and detailed as expected. In large collaboratories such as Collaboratories F and G, the large number of documents makes it difficult to locate information.

One complication with science is that much of the knowledge that is shared is *tacit*. Such tacit knowledge is extremely difficult to acquire through distance communication technologies and can only be shared through on-site observation and participation. In order to build general competence, it is important for scientists to have long-term exposure to practices of scientists from developed countries. Information technology cannot fulfill this goal.

THEORETICAL IMPLICATIONS

Scientists participate in collaboratories with the hopes of overcoming the limitation of their local organizations, accessing resources and experts in other organizations, and ultimately increasing their productivity. I found that collaboratories enable scientists from developing countries to overcome difficulties resulting from isolation and allow them to reach resources and engage in communities of practice with scientists from developed countries. In order to better understand how scientists can maximize the benefits from collaboratories, it is important to differentiate various attributes of collaboratories, such as dependency relationship among scientists, geographical dispersion, and funding situations in different collaboratories. These characteristics affect the way in which scientists from developing countries can access scientists and their practices in the developed world.

The factors that differentiate collaboratories listed above are not intended to be exhaustive. Rather, one important area of future research is to further develop and sharpen these attributes that affect collaboration between scientists from developing and developed countries. Collaboratory researchers need to change the focus of analysis from evaluating the impact of a collaboratory as a whole to individual factors affecting scientists' participation in collaboratories. This approach will have important implications for policy and design.

The study also has implications for the theory of CoPs and NoPs. The findings confirm Osterlund and Carlisle's(2005) conclusion that in order to gain a better understanding of communities of practice, there is a general need to look more closely at "cross-communal infrastructure of social practices" (p98).

First, the findings of the study reveal the influence of multimembership and cultural differences on people's participation in CoPs and NoPs. As discussed in the literature review, Wenger's (1998) discussion of multimembership remains abstract, because his empirical example comes from a single community. By studying collaboratories, seen as communities consisting of multiple communities of practice, we could see that the communication infrastructure, national and organizational culture and social practices in one community that scientists belong to can affect their access to old timers and practices in another community. For example, high teaching load and poor communication infrastructure hinders scientists from Morrocco and South Africa from participating in communities of practice and networks of practices in Collaboratories F and G; hierarchical culture constitutes a greater barrier for junior Chinese scientists to access communities of practice and networks of practice than senior scientists.

Second, this study shows the impact of the dependencies and tensions in cross-communal relations on knowledge and practice sharing. When one community relies on the other community for resources, there tends to be fewer barriers to knowledge and practice transfer. For example, when US scientists rely on Chinese scientists for data collection, they are more willing to transfer technologies to Chinese scientists. By contrast, when there is no dependency relationship, more experienced people are less motivated to share their practices with those who are less experienced. The study also indicates that tensions in cross-communal relations can generate changes in the involved parties. For example, community members from different organizations tend to have expectations for others. When these expectations are not met, knowledge or practice sharing tend to be hindered. For example, in Collaboratory F, when French scientists found that Chinese scientists could not offer as much intellectual contribution as expected, they became less motivated to work with Chinese scientists.

In this light, the findings demonstrate that to understand CoPs and NoPs more completely, the analysis should not only include high-level analysis, such as the community and practice, but also attributes of individual participants, such as their multimembership in different communities, as well as the dependency and tension among them. By doing so, we can draw on an extensive literature of individual motivations and group and organizational behavior.

This study also reveals the mediating factors that affect the relationship between information technology and scientific productivity. Information technology, such as video and teleconference can increase chances for participation in communities of practice. Whether the potential of these technologies can be realized depends on the whether the participants can be present at the same time and the sophistication of communication infrastructure. Benefits of these systems can be enhanced if the participants have prior encounters, so the ability to travel will be important. Moreover, as discussed previously, information technology has its limitations. Current technologies cannot support many practices crucial for scientific performance. For example, what is shared and learned through working side by side cannot be achieved at distance. Thus, when we study the impact of information technology on scientific productivity, we should not overlook the "necessary intermediaries" such as the nature of scientific work, institutional contexts, and relationship of collaborators (Brown & Duguid, 2000).

POLICY IMPLICATIONS

This work has several important policy implications. First, participating in collaboratories enables scientists to gain funds from either the collaboratories or their local funding agencies to build infrastructure for future research. However, funds for infrastructure tend to be concentrated on advanced instruments, such as machines, computers, etc. Less attention has been directed to infrastructure in terms of opportunities for communication. Results of this work suggest that communication among scientists from different labs critically aid scientists in their exchange of information and experience. Due to poor communication infrastructure, scientists from developing countries cannot participate in video or teleconferences as frequently as desired. Nor could scientists from developing countries travel to conferences and workshops as often as their collaborators in developed countries, leaving them fewer opportunities to engage in face-to-face communication with other scientists. Thus, funding agencies should invest funds to both help scientists build communication infrastructure, and facilitate travel.

In all the collaboratories considered herein, the relationships between scientists from developing countries and the developed world resembles those between colonial scientists in Africa and western scientists during the period of colonial science described by Basalla (1967). The interests of scientists from developing countries are directed by those from the developed world. Scientists from developed countries tend to focus on transferring to scientists from developing countries technologies and practices needed for specific projects on which they work. However, to improve their capacity so that they can collaborate with scientists from developed countries on an equal footing, scientists from developing countries need more than technology transfer. They need to engage in communities of practices which allow them to acquire full research capacity, such as the ability to design experiments and perform data analysis. Collaboratories neglect this need.

In addition, this work also finds that the governmental policies of developing countries sometimes hinder international collaboration among collaboratory members. Scientists and policy makers need to gain mutual understanding, and policy makers should provide scientists with more support.

DESIGN IMPLICATIONS

Scientists in collaboratories benefit from various information technologies, such as web forums and databases that enable them to exchange ideas and experiences, as well as video and teleconferences, that allow them to engage in real-time communication even when they are distributed. However, these benefits can be maximized if the use of technologies is improved:

First, some information technologies (such as databases and wikis), are efficient tools for scientists to record their working progress, research methodology and failure experiences. Such record-keeping enables scientists from developing countries to communicate and learn from scientists from developed countries. However, unaware of these benefits to others, scientists often forget to record their work. Thus, participants of collaboratories should be reminded from time to time that their partners are remotely located; thus, they should record their activity and research methods, and share them with their partners. In addition, the posted documents are not always as organized and detailed as desired. Thus, collaboratories need to encourage the participant site to conduct document management to ensure the quality of online documents. Collaboratory members from different countries who speak different languages tend to document their work in their own languages. They should be encouraged to record their work in English so that scientists speaking other languages can understand their documents.

Second, when a large amount of information is available, scientists find it difficult to locate information. Collaboratories need to pay attention to scientists' need for information seeking, and employ better information architecture or alternative practices to annotate and characterize information (e.g. social tagging).

Finally, since in some developing countries, scientists cannot afford high-end technologies, collaboratories should look for solutions that do not require highly advanced communication infrastructure. For example, instead of video conferencing technologies, they can apply low bandwidth technologies that also allow data sharing with voice over IP (e.g., Centra).

LIMITATIONS OF THE STUDY

Limitations of the study mainly result from the sampling method adopted:

As mentioned in Chapter 3, the collaboratories studied for the research were selected from a database of collaboratory projects (see www.scienceofcollaboratories.org). Collaboratories in this database were chosen using snowball sampling, that is, one collaboratory identified informed the researcher about another collaboratory, which in turn provided information of the third collaboratory, and so on. In each of the collaboratories studied for the current research, snowball sampling method was used again to identify participants. The PIs were contacted first. They introduced the researcher to the collaboratory participants, and then the participants would introduce the researcher to their collaborators, and so on.

Snowball sampling is particularly helpful when members of a special population are difficult to locate (Atkinson & Flint, 2001). In the case of this study, it was difficult to identify collaboratory projects as well as the participants in different collaboratories. Snowball sampling provided an economic and efficient way for the researcher to identify collaboratories and participants suitable for the study. Snowball sampling method also facilitated the researcher to develop trust with the participants, because referrals were made by acquaintances or peers rather than other more formal methods of identification. This was particularly helpful for the researcher to build rapport with the participants when conducting interviews (Atkinson & Flint, 2001) .

However, because elements are not randomly drawn, but are dependent on the subjective choices of the respondents first accessed, snowball sampling method tends to generate biased samples, and thus do not allow the researcher to generalize from a particular sample (Griffiths, Gossop, Powis, & Strang, 1993). In the current research, most collaboratories selected are US based. It is difficult to know if the findings of the study apply to other types of collaboratories. For example, in recent years, more and more collaboratories have been formed in Europe, and these collaboratories require participation from less developed countries in Eastern Europe. Whether the findings of the current study apply to these collaboratories deserves future study. In addition to selection bias, there is also the issue of gatekeeper bias in snowball sampling (Groger, P., & Straker, 1999). Playing the role of gatekeepers, participants first identified may only refer to the researchers whom they like or whom they think are appropriate for the study, which hinders the researcher's access to a larger population. In the case of the current study, the respondents may have been less likely to refer the researcher to the collaborators with whom they disagree, whom they do not like or those who might have negative opinions towards them.

In spite of these limitations, I have provided a deep foray into the issues of collaboratories with scientists from developing countries, and thereby set the stage for future research.

FUTURE RESEARCH

Several topics emerge as rich and important subjects for further investigations based on the findings of the study, which collectively describe an agenda for future research focused on the following areas: (1) further investigation into the factors important to successful collaboration between scientists from developing and developed countries; (2) validating these success factors; (3) examining whether the success factors hold true for collaboratories where the developing countries become the dominant sites; (4) developing a theoretical understanding of cross-cultural collaboration between scientists from developing and developed countries.

The study was conducted when scientists in the collaboratories studied worked on data collection. It is expected that there will be social, cultural and technical factors other than those identified in the current study that will affect scientists' collaboration when they begin work related to data sharing and publications. A follow-up study is needed to understand those factors.

Based on my dissertation, and drawing from the literature on cognitive, social science and organizational behavior, a set of working hypotheses can be formulated about factors that define successful collaboration between scientists from developing and developed countries. In future research, these hypotheses can be systematically evaluated and tested through a survey of a larger number of projects and scientists.

The conclusions of the study are based on interviews of collaborators in collaboratories in which the dominant sites are in the US and Europe. Recently, there have been developments in China whereby the government has spent very large amounts of money to develop a very sophisticated High Energy Physics site (Overbye, 2006). The physicists in China have an opportunity to become the dominant scientists. In future research, we can investigate this new collaboratory, which will allow us to determine which of the success factors defined in the collaboratories I have examined to date hold when the "tables are turned." Which of the prescriptions for success are predicated on the fact that the lead organization is from the developed world? What changes when the lead organization is from a traditionally developing country that now has the lead in technological sophistication?

To summarize all the above studies, we can expect to develop a theoretical understanding of cross-cultural collaborations, whether centered within or without the US and Europe, and at a practitioner-level to prescribe to future collaborations how to make these endeavors successful.

APPENDIX A

INTERVIEW PROTOCOL

FOR SCIENTISTS PARTICIPATING IN COLLABORATORIES

Background knowledge

1. Before you participated in this project, had you ever collaborated with scientists from other institutions?
2. If you had, who did you collaborate with?
3. How did that collaboration happen?
4. When did you get involved in this project?
5. How did you get involved in this project?
6. What is your role in this project?
7. What are the main funding resources of this project?
8. What are your funding resources in general?
9. If you are a PI, do you have the power to use the funding at your will?
10. How many hours do you teach each week?
11. How many research assistants do you have?
12. What is rewarding structure in your institution?

Task of collaboration

1. Are tasks done with this project all of a certain type, or is there a great diversity in the types of tasks?
2. How do you usually use the collaboratory?
3. If there is no 'typical' task, please list several types of things that have been done.
4. If there are some typical tasks, please describe what they are like.

General Questions

1. How do you think the collaboratory benefits you?
2. What are the barriers to participating in collaboratories?
3. In this collaboratory, you are collaborating with some scientists from developing (developed) countries. Are there any problems caused by that?

Collegial Communication

1. How often do you communicate with your collaborators?
2. Usually what is the purpose of communication?
3. How often do you attend the annual meetings organized by the collaboratory?
4. How often do you email your collaborators?
5. What is your last experience of contacting your partners? What did you do? What did you ask them?
6. Could you describe the most productive interaction between you and your collaborators?
7. Could you give an example of miscommunication between you and your collaborators?

8. On what occasions do you think you have to meet your collaborators face-to-face?

Group identity

1. What does it mean for you to be a member of the collaboratory?
2. Do you feel part of the collaboratory?
3. Are you willing to put in a great deal of effort beyond that normally expected in order to help the collaboratory to be successful?
4. To what extent are the people in the collaboratory helpful in getting your job done?
5. To what extent do you trust the members of your collaboratories?
6. When there is time conflict between a project that you are collaborating with your local colleagues and your task in the collaboratory, which project do you think has the priority?
7. If you have a new research idea, or if you have a research question, with whom do you often discuss it?

Status difference

1. If you want to coauthor a paper with another collaboratory member, whom you want to work with the most?
2. Whom you don't want to work with? Why?

Communication technologies

1. How do you communicate with other collaboratory members? By email? By fax? Or by instant messaging?

2. On what occasions do you use the technologies?
   (also ask why they don't use a certain type of technology, if it applies.)

Sharing Resources

1. What kind of data you can share with other collaboratory members?
2. What kind of data you do not want to share with other collaboratory members?
3. Are there any collaboratory members you don't want to share data with? Why?

Technological Barriers

1. Did you have any difficulty interfacing with technologies in collaboratories?
2. Are there any barriers to sharing instrument or sharing data resource that are caused by technology infrastructure?

Catch-all

1. What do you think the strengths of this project are? (prompt to speculate on why?)
2. What do you think the weaknesses of this project are? (prompt to speculate on why?)
3. What should I have asked you to tell me about this project but didn't?

APPENDIX B

INTERVIEW PROTOCOL FOR ADMINISTRATORS.

1. What are the major developing countries participating in the collaboratories?
2. What are the timelines for each country's participation?
3. Usually how did they get involved?
4. What are the forms of their participation?
5. How do you decide which countries can participate? Do you need to do some evaluation work?
6. How does the countries' participation become different in the process?
7. What do you think are the benefits for scientists from developing countries to participate in the collaboration?
8. How do you think X Collaboratory benefits from the participation by scientists from the developing countries?
9. How do you think scientists from the developed world will benefit from the participation by scientists from the developing countries?
10. What are the efforts for X Collaboratory to promote the participation of scientists from developing countries?
11. What are the efforts for X Collaboratory to integrate scientists from different countries of the world?
12. What are the special difficulties for scientists from the developing countries?

13. What are the special difficulties to organize collaboration between scientists from developing and developed countries?
14. There are scientists from many developing countries who are participating in the collaboration, what are the differences in terms of difficulties they encounter?
15. What are the roles of collaborative tools?
16. How do you think the collaboratory can be improved

APPENDIX C

CODEBOOK FOR SCIENTISTS INTERVIEWS

The interview protocol included direct questions on these topics that were asked of all the scientists. One aspect of the use of these codes is to identify and index the answers to these questions.

Prior experiences of collaboration—general: Scientists' experiences of collaborating with scientists outside their own institutions before the beginning of collaboratories.

Prior experiences of collaboration—with other collaboratory members: Scientists' experiences of collaborating with other scientists who are currently in the same collaboratories, but outside their own institutions before the beginning of collaboratories

Tasks: tasks that scientists accomplish via collaboration

Junior scientists: doctoral students and postdoctoral fellows

Senior scientists: experienced scientists who are capable to advise doctoral students and postdoctoral fellows

Benefits: Any benefits scientists list from collaboratories. Note the code is used to record benefits for scientists from both developing and developed countries.

Barriers: Any barriers scientists list to participating in collaboratories. Nott the code is used to record barriers for scientists from both developing and developed countries.

Building fields of connection (access people)—remotely: how scientists build bonds with and gain attention from each other when they are not co-located.

Building fields of connection (access people)—co-located: how scientists bond with and gain attention from each other when they are co-located. Note the node also records the situations in which scientists think they must be co-located and communicate face-to-face.

Access practices—remotely: how scientists from developing countries access the practices of scientists from developed countries when they are not co-located.

Access practices—co-located: how scientists from developing countries access the practices of scientists from developed countries when they are co-locate. Note this node also records the situations in which scientists think they can only access others practices when they are co-located.

Improvements—what scientists think that collaboratories should be improved to maximize their benefits

APPENDIX D

CODE BOOKS FOR ADMINISTRATORS

The interview protocol included direct questions on these topics that were asked of administrators of collaboratories. One aspect of the use of these codes is to identify and index the answers to these questions.

Standard for participation—how collaboratories decide which developing countries can participate

Ad-Benefits-collaboratories—administrators' point of view of how collaboratories benefit from the participation by scientists from developing countries

Ad-Benefits-developing countries—administrators' point of view of how collaboratoreis benefit scientists from developing countries

Ad-Benefits (developed countries)—administrators' point of view of how collaboratories benefit scientists from developed countries

Promotion (scientists from developing countries)—how collaboratories promote participation of scientists from developing countries

Integration—how collaboratories try to integrate scientists from different countries

Ad-Difficulties (developing countries)—Administrators' point of view of the difficulties for collaboratories to support collaboration between scientists from developing and developed countries

APPENDIX E

RECRUITING LETTER

I am a doctoral candidate at the University of Michigan's School of Information, working with Professor Judy Olson. We have a large scale NSF sponsored project to study colloboratories, which help scientists to collaborate with each other across distance and institutions.

As part of that study, I am investigating how collaboratories affect the work of scientists from different sizes and types of institutions. The ultimate goal of my study is to improve our understanding of the cultural, political, and technical factors that influence scientific collaboration.

I am writing to you because I know from the XX Collaboratory website that you have been participating in XX Collaboratory, and hope you might be willing to share with me your experiences of being a member of XX Collaboratory. I am interested in how scientists from different countries collaborate with each other and benefit from such collaboration.

Would you please grant me an interview? Your participation in this project would greatly benefit our understanding of what makes collaboratories successful. I will highly appreciate your help. All the data collected will be confidential. Only my adviser and I will see the data.

If you are willing to participate in my study, please let me know what time would be convenient for an interview. Thank you for considering my request.

Sincerely,

Airong Luo

Doctoral candidate

School of Information

University of Michigan

Phone number: 1-734-XXXXXXX

Email:

APPENDIX F

IMPERFECT PARTNERSHIP: EFFECTS OF COLLABORATORIES ON SCIENTISTS FROM DEVELOPING COUNTRIES

INFORMED CONSENT FOR INTERVIEWS

Purpose

My name is Airong Luo, and I am a graduate student of School of Information at the University of Michigan-Ann Arbor. I am working on a doctoral dissertation study called “How Collaboratories Affect Peripheral Scientists”. The ultimate goal of my study is to improve our understanding of the cultural, political, and technical factors that influence collaboratory use.

Procedures

If you agree to participate in the study, I will interview you at a time and place that is convenient for you. The interview will last an estimated 1 to 2 hours. We will talk about your experiences of being a member of a collaboratory, how collaboratories benefit you, and the barriers of using a collaboratory.

With your consent, the interview will be tape recorded so that our conversation can be recalled accurately. If you do not consent to be tape recorded, but do consent to the interview, the interview can still be conducted.

Risks and discomforts

The researcher does not expect that participating in the study will cause you any side effects, physical or psychological discomfort, or expose you to any risks. The interview can be stopped at any time if you do not wish to continue for any reason.

Benefits

There is no direct benefit of your participation. However, as a study participant, you will have an opportunity to help funding agencies and information professionals understand better what makes scientific collaboration and collaboratories successful.

Voluntary participation

Your participation in this project is voluntary. You may refuse to participate before the study begins, discontinue at any time, or skip any questions that make you feel uncomfortable or in any way negatively affect you. Even after you sign the informed consent form, you may decide to leave the study at any time without penalty. You are free to ask questions about the study at any time and to decline to provide any information or answer any questions that you do not wish to answer.

Confidentiality

Your name and any information that could be used will always be kept confidential. All information collected for this study, including the cassette tape(s) and notes from your interview, will be stored securely in a locked file cabinet and identified only with a code number. The code key connecting the name to the numbers will be kept in a separate location. The researcher will have access to the interview notes with identifying information; the researcher and a transcriptionist will have access to the cassette tape(s). Records will be kept confidential to the extent provided by federal, state, and local law; however, the Institutional Review Board, which is responsible for monitoring this study, may inspect these records. Upon completion of the study, the tapes will be archived in a locked file cabinet and after 5 years, these tapes will be destroyed.

Future use of data

Information from the interview may appear in my dissertation, or in papers, books, or lectures; however, your name and other identifying information will never be used. You are invited to have copies of any materials that are written using the information collected in this study. I welcome any comments that you would like to make on the materials produced.

Documentation of the consent

One copy of this document will be kept together with the research records of this study. Also, you will be given a copy to keep.

Contact information of the investigator

Primary Investigator: Airong Luo, doctoral student, School of Information, University of Michigan.

Tel. 734-7632285

Faculty Adviser: Judy Olson, Professor, School of Information, Business School, Department of Psychology, University of Michigan

Tel. 734-7632285

Should you have questions regarding your rights as a participant in research, please contact the Institutional Review Board, Behavioral Sciences, 540 E. Liberty #202, Ann Arbor, MI 48104, (734) 936-0933, email: irbhsbs@umich.edu

Please sign below if you are willing to have this interview tape recorded. You may still participate in this study if you are not willing to have the interview recorded.

Signature ___________________________

Date______________________________

Consent of the subject:

I have read of the information given above. Airong Luo has offered to answer any questions I may have concerning the study. I hereby consent to participate in the study.

Printed Name ____________________________ Consenting signature __________________

BIBILIOGRAPHY

Allen, T. J. (1977). *Managing the flow of technology*. Cambridge, Masachusetts: The MIT Press.

Allison, P. D., & Long, J. S. (1990). Departmental effects on scientific productivity. *American Sociological Review, 39*, 596-606.

Allison, P. D., & Stewart, J. A. (1974). Productivity Differences among Scientists: Evidence for Accumulative Advantage. *American Sociological Review, 39*(4), 596-606.

Ambrosini, V., & Bowman, C. (2001). Tacit knowledge: some suggestions for operationalization. *Journal of management studies, 38*(6).

Annan, K. (2003). A challenge to the world scientists. *Science, 299*, 1485.

Atkinson, R., & Flint, J. (2001). Accessing Hidden and Hard-to-Reach Populations: Snowball Research Strategies. *Social Research Update, 33*.

Bassala, J. (1967). The Spread of Western Science. *Science, 156*(5), 611.

Bechky, B. A. (2003). Sharing meaning across occupational communities: the transformation of understanding on a production floor. *organization Science, 14*(3), 312-330.

Bechy, B. A. (2003). Sharing meaning across occupational communities: the transformation of understanding on a production floor. *organization Science, 14*(3), 312-330.

Bishop, A. P. (1994). The Role of Computer-Networks in Aerospace Engineering. *Library Trends, 42*(4), 694-729.

Boland, R. J., & Tenkasi, R. V. (1995). Perspective making and perspective taking: In communities of knowing. *Organization Science, 9*, 605-622.

Brown, J. S., & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a Unified View of Working, learning and innovation. *Organization Science, 2*(1), 40-57.

Brown, J. S., & Duguid, P. (1998). Organizing Knowledge. *California Management Review, 40*(3), 90-111.

Brown, J. S., & Duguid, P. (2000). *The social life of information*. Boston, Massachusetts: Harvard Business School Press.

Brown, J. S., & Duguid, P. (2001). Knowledge and organization: a social-practice perspective. *12*(2), 198(117).

Burke, K., Aytes, K., Chidambaram, L., & Johnson, J. J. (1999). A study of partially distributed work groups: the impact of media, location, and time on perception and performance. *Small Group Research, 30*(4), 453-490.

Carlie, P. (1998). From transfer to transformation: Working through knowledge boundaries in product development. .

Chubin, D. E., Porter, A. L., & Boeckmann, M. E. (1981). Career patterns of scientists: A case for complementary data. *American Sociological Review, 46*(4), 488-496.

Clark, H. H., & Brennan, S. E. (1991). Grounding in Communication. In L. B. Resnick, R. M. Levine & S. D. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 127-149). Washington DC: APA.

Cohen, J. (1996). Computer mediated communication and publication productivity among faculty. *Internet Research-Electronic Networking Applications and Policy, 6*(2-3), 41-&.

Constant, D., Sproull, L., & Kiesler, S. (1996). The kindness of strangers: The usefulness of electronic weak ties for technical advice. *Organization Science, 7*(2), 119-135.

Corsini, R. (1987). *Concise Encyclopedia of Psychology*. New York: Wiley.

Cox, A. (2005). What are communities of practice? A comparative review of four seminal works. *Journal of Information Science, 31*(6), 527-540.

Crane, D. (1965). Scientists at major and minor universities: a study in productiviety and recognition. *American Sociological Review, 30*(5).

Crestwell, J. W. (2007). *Qualitative inquiry and Research Design*. Thousand Oaks, California: Sage Publications.

Creswell, J. W. (1994). *Research Design: Qualitative & quantitative approaches*. Thousand Oaks, California: Sage publication.

Cummings, J., & Kiesler, S. (2005). Collaborative research across disciplinary and organizational boundaries. *Social Studies of Science, 35*(5), 703-722.

Davidson, T., Sooryamoorthy, R., & Shrum, W. (2002). Kerala Connection: Will the Internet affect science in developing areas? In B. Wellman & C. Haythornthwaite (Eds.), *The Internet in Everyday Life*: Blackwell.

Dennis, A. R. (1996). Information exchange and use in group decision making: You can lead a Group to information, but you can't make it think. *MIS Quarterly, 20*(4), 591-626.

DiMaggio, P., E., Hargittai, W. N., & J.P., R. (2001). Social implications of the Internet. *Annual Review of Sociology, 27*, 307-336.

Duque, R. B., Ynalves, M., Sooryamoorthy, R., Mbatia, P., Dzorgbo, D.-B., & Shrum, W. (2005). The collaboration Paradox: Scientific productivity, the Internet, and Problems of Research in Developing Areas. *Social Studies of Science, 35*(5), 755-785.

Finholt, T. A. (2002). Collaboratories. *Annual Review of Information Science and Technology, 36*, 73-107.

Finholt, T. A., & Sproull, L. (1990). Electronic groups at work. *Organization Science, 1*, 41-64.

Fontana, A., & Frey, J. H. (2000). The interview: From structured questions to negotiated text. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 645-672). Thousand Oaks: Sage Publications.

Fox, M. F. (1991). Research productivity and the environmental context. In T. G. Whiston & R. L. Geiger (Eds.), *Research and Higher education: The United Kingdom and the United States* (pp. 103-111). Buckingham, England: Social Research into Higher Education/Open University press.

Fox, S. (2000). Communities of practice, Foucault and actor-network theory. *Journal of management studies, 37*(6), 853-867.

Gaillard, J. (1991). *scientists in the third world*. Kentucky: The University Press of Kentucky.

Godin, B., & Gingras, Y. (2000). Impact of collaborative research on academic science. *Science and Public Policy, 27*(1), 65-73.
Goldfinch, S., Dale, T., & Derouen, K. (2003). Science from the periphery: Collaboration, networks and 'periphery effect' in the citation of Newzealan Crown Research Institutes articles, 1995-2000. *Scientometics, 57*(3), 321-337.
Griffiths, P., Gossop, M., Powis, B., & Strang, J. (1993). Reaching hidden populations of drug users by privileged access interviewers: methodological and practical issues. *Addiction, 88*, 1617-1626.
Grinter, R. E., Herbsleb, J. D., & Perry, D. E. (1999). the geography of coordiantion: dealing with distance in R & D Work. *Proceedings of the GROUP 99 Conference of the ACM*, 306-315.
Groger, L., P., M., & Straker, J. (1999). What we didn't learn because of who would not talk to us. *Qualitative Health Research, 9*(6), 829-835.
Hammersley, M. (1992). *What's wrong with ethnography: Methodological explorations.* London: Routledge.
Hargens, L. L., & Hagstrom, W. O. (1967). Sponsored and Contest Mobility of American Academic Scientists. *sociology of education, 40*(1), 24-38.
Hedlund, G. (1994). A model of knowledge management and the N-form corporation. *strategic management journal, 15*, 73-90.
Herbsleb, J. D., Mockus, A., & Finholt, T. A. (2000). Distance, dependencies, and Delay in Global Collaboration. *Proceedings of the conference on computer-supported cooperative work*, 3-17.
Hesse, B. W., Sproull, L. S., Keisler, S. B., & Walsh, J. P. (1993). Returns to science: Computer networks in oceanography. *Communications of the ACM, 36*(8), 90-101.
Hildreth, P. (2000). communities of practice in the distributed international environment. *Journal of knowledge management, 4*, 27-38.
Holmgren, M., & Schnitzer, S. A. (2004). Science on the rise in developing countries. *PLoS Biology, 2*(1), 11-13.
Jackson, S. (2003). Territorial(izing) Knowledge: Thinking Through the Spaces of Science
. Department of Communication, University of California, San Diego.
Johnson, R. B. (1997). Examining the validity structure of qualitative research. *Education, 118*(2), 282-291.
Kaminer, N., & Braunstein, Y. M. (1998). Bibliometric analysis of the impact of Internet Use on scholarly productivity. *Journal of the Amercian Society for Information Science, 49*(8).
Kiesler, S., & Cummings, J. (2002). Proximity and distance in work groups. In P. J. Hinds & S. Kiesler (Eds.), *Distributed Work* (pp. 57-80). Cambridge, Massachusetts: MIT Press.
Knorr-Cetina, & Karin. (1999). *Epistemic Cultures: How the Sciences Make Knowledge.* Cambridge, Massachusetts: Harvard University Press.
Knorr-Cetina, K. (1981). *The manufacture of knowledge*. Oxford: Pergamon Press.
Kogut, B., & Zander, U. (1992). Knowledge of the firm, combinative capabilities, and the replication of technology. *Organization Science, 3*, 383-396.

Koku, E. F., & Wellman, B. (2004). Scholarly Networks as Learning Communities: the case of technet. In S. Barab & R. Kling (Eds.), *Desining Virtual Communities in the Service of Learning* (pp. 229-337). Cambridge: Cambridge University Press.

Kraut, R., Egido, C., & Galegher, J. (1988). Patterns of contact and communication in scientific research collaboration. *Computer Supported Cooperative Work 1988 proceedings*, 1-12.

Kraut, R., Fish, R. S., Root, R. W., & Chalfonte, B. (1990). Informal communication in organizations: Form, function, and technology. In S. Oskamp & S. Spacapan (Eds.), *Human Reactions to Technology: The claremont symposium on applied social psychology* (pp. 145-199). Beverly Hills, CA: Sage Publications.

Kraut , R. E., & Egido, C. (1990). Patterns of Contact and communication in scientific research collaboration. In *Intellectual teamwork: Social and Technological Foundations of Cooperative Work* (pp. 149-171). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Lam, A. (1997). Embedded firms, embedded knowledge: problems of collaboration and knowledge transfer in global cooperative ventures. *organizational studies, 18*(6), 973-996.

Latour, B., & Woolgar, S. (1986). *Laboratory Life: the construction of scientific facts*. Princeton, New Jersey: Princeton University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Lee, S., & Bozeman, B. (2005). The impact of Research Collaboration on Scientific Productivity. *Social Studies of Science, 35*(5), 673-702.

Long, J. S. (1978). Productivity and academic position. *American Sociological Review, 43*(6), 889-908.

Long, J. S., & McGinnis, R. (1981). Organizational context and scientific productivity. *American Sociological Review, 46*(4).

Luo, A. (2006, November). *Informal Communication in Collaboratories.* Paper presented at the Annual Meeting of the American Society of Information Science and Technology, Austin, Texas, USA.

Luo, A., & Olson, J. S. (2008). How collaboratories affect scientists from developing countries. In G. Olson, A. Zimmerman & N. Bos (Eds.), *Science on the Internet*. Cambridge: MIT Press.

Lynch, M. (1985). *Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory*: Routledge Kegan & Paul

Malone, T. W., & Crowston, K. (1994). the interdisciplinary study of coordination. *ACM computing surveys, 26*(1), 87-119.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis*. Thousand Oaks, California: Sage Publication.

Nardi, B. (2005). Beyond Bandwidth: Dimensions of Connection in Interpersonal Communication. *Computer Supported Cooperative Work* (14), 91-130.

Nardi, B., & Whittaker, S. (2002). The Place of Face-to-Face Communication in Distributed Work. In P. J. Hinds & S. Kiesler (Eds.), *Distributed work* (pp. 83-110). Cambridge, Massachusetts: MIT press.

Olson, G. M., Bos, N., & Zimmerman, A. (2008). Introduction. In G. M. Olson, N. Bos & A. Zimmerman (Eds.), *Science on the Internet*. Cambridge: MIT Press.

Olson, G. M., & Olson, J. S. (2000). Distance matters. *Human-Computer Interaction, 15*, 139-178.
Olson, J. S. (2008). The Birn Collaboratories. In G. M. Olson, B. Nathan & A. Zimmerman (Eds.), *Science on the Internet*. Cambridge: MIT.
Olson, J. S., Hofer, E., Bos, N., Zimmerman, A., Olson, G. M., Cooney, D., et al. (2008). A theory of Remote scientific collaboration (TORSC). In G. M. Olson, A. Zimmerman & N. Bos (Eds.), *Science on the Internet*. Cambridge: MIT Press.
Orlikowski, W. J. (1994). Technological Frames: Making Sense of Information Technology in Organizations. *ACM Transactions on Information Systems*.
Orlikowski, W. J. (2002). Knowing in Practice: Enacting a Collective Capability in Distributed Organizing. *Organization Science, 13*(3), 249-273.
Orr, J. E. (1996). *Talking about machines: An ethnography of a modern job*. New Yori: ILR Press.
Osterlund, C., & Carlie, P. (2005). Relations in practice: sorting through practice theories on knowledge sharing in complex Organizations. *The Information Society, 21*, 91-107.
Pelz, D. C., & Andrews, F. M. (1976). *Scientists in organizations: productive climates for research and development*. Ann Arbor, Michigan: Institute for social research.
Polanyi, M. (1966). *The tacit dimension*. New York: Doubleday & Co.
Pravdic, N., & Oluic-Vukovic, v. (1986). Dual apprach to Multiple authorship in the study of collaborator and scientific output relationship. *scientometics, 10*(5/6), 259-280.
Price, D. J. d. S. (1971). some remarks on elitism in information and the invisible college phenomenon in science. *Journal of the american society for information science*(22), 74-75.
Price, D. J. d. S., & Beaver, D. (1966). Collaboration in an invisible college. *American Psychologist, 21*(11), 1011-1018.
Reskin, B. F. (1979). Academic sponsorship and scientists' career. *Sociology of Education, 52*(3), 129-146.
Riddoch, I. (2000). Bridging the quality gap. *Nature 408*(6811), 402.
Roberts, T. L. (1998). Are newsgrops virtual communities. *SIGCHI 1998*, 360-367.
Saunders, C., Van Slyke, C., & Vogel, D. R. (2004). My time or yours? Managing time visions in global virtual teams. *Academy of managment executive, 18*(1), 19-31.
Seale, C. (1999). *The Quality of Qualitative Research*. Thousand Oaks, California: Sage Publication.
Sole, D., & Edmondson, A. (2002). Situated knowledge and learning in dispersed teams. *British Journal of management, 13*, 17-34.
Star, S., & Griesemer, J. (1989). Institutional ecology, 'translation,' and boundary objects: Amateurs and professionals in Berkeley's Museum of Vertebrate Zoology 1907-1939. *Social Studies of Science, 19*, 387-420.
Taylor, S. J., & Bogdan, R. (1998). *Introduction to qualitative research methods: A guidebook and resource*. New York: John Wiley.
Traweek, S. (1992). *Beamtimes and Life times: the world of high energy physicists*. Cambridge: Harvard University Press.
UNESCO. (2005). *UNESCO Science Report 2005*: UNESCO publishing.

Wagner, C. S. (2001). *Science and technology collaboration: Building capacity in developing countries*: Rand Science and Technologyo. Document Number)
Walsh, J. P., & Bayma, T. (1996). The Virtual College: Computer-Mediated Communication and Scientific Work. *The Information Society, 12*, 343-363.
Walsh, J. P., Kucker, S., Maloney, N. G., & Gabbay, S. (2000). Connecting minds: Computer-mediated communication and scientific work. *Journal of the American Society for Information Science, 51*(14), 1295-1305.
Walsh, J. P., & Maloney, N. G. (2002). Computer Network Use, Collaboration Structures, and Productivity. In P. J. Hinds & S. Kiesler (Eds.), *Distributed Work*. Cambridge: The MIT Press.
Walsh, J. P., & Maloney, N. G. (2003). Scientific productivity, new communication technology and inequality: Does CMC narrow the gap? In *unpublished*.
Walsh, J. P., & Maloney, N. G. (2007). Collaboration structure, communication media, and problems in scientific work teams. *Journal of Computer-Mediated Communication 12*(2), 712-732.
Weisband, S. P., Schneider, S. K., & Connolly, T. (1995). Computer-mediated communication and social information: status and status differences. *Academy of management journal, 38*(4), 1124-1151.
Weisss, R. S. (1994). *Learning from strangers: The art and method of qualitative interview studies*. New York: The Free Press.
Wenger, E. (1999). *Communities of practice: learning, meaning and identity*: Cambridge University Press.
Williams, D., Bona, M., Butterworth, I., Davies, D., Jaume-Rajaonia, S., Mayer, T., et al. (2003). *Study into European Research and Education Networking As Targeted by Europe*: SERENATEo. Document Number)
Winter, S. G. (1987). Knowledge and competence as strategic assets. In D. J. Teece (Ed.), *The competitive challenge*. Cambridge, MA: Ballinger Publishing Company.
Zuckerman, H. (1967). Nobel laureates in science: Patterns of productivity, collaboration, and authorship. *American sociological review, 32*(3), 391-403.
Zuckerman, H. (1988). The Sociology of Science. In J. S. Neil (Ed.), *Handbook of Sociology* (pp. 511-574). Newbury Park: Sage.